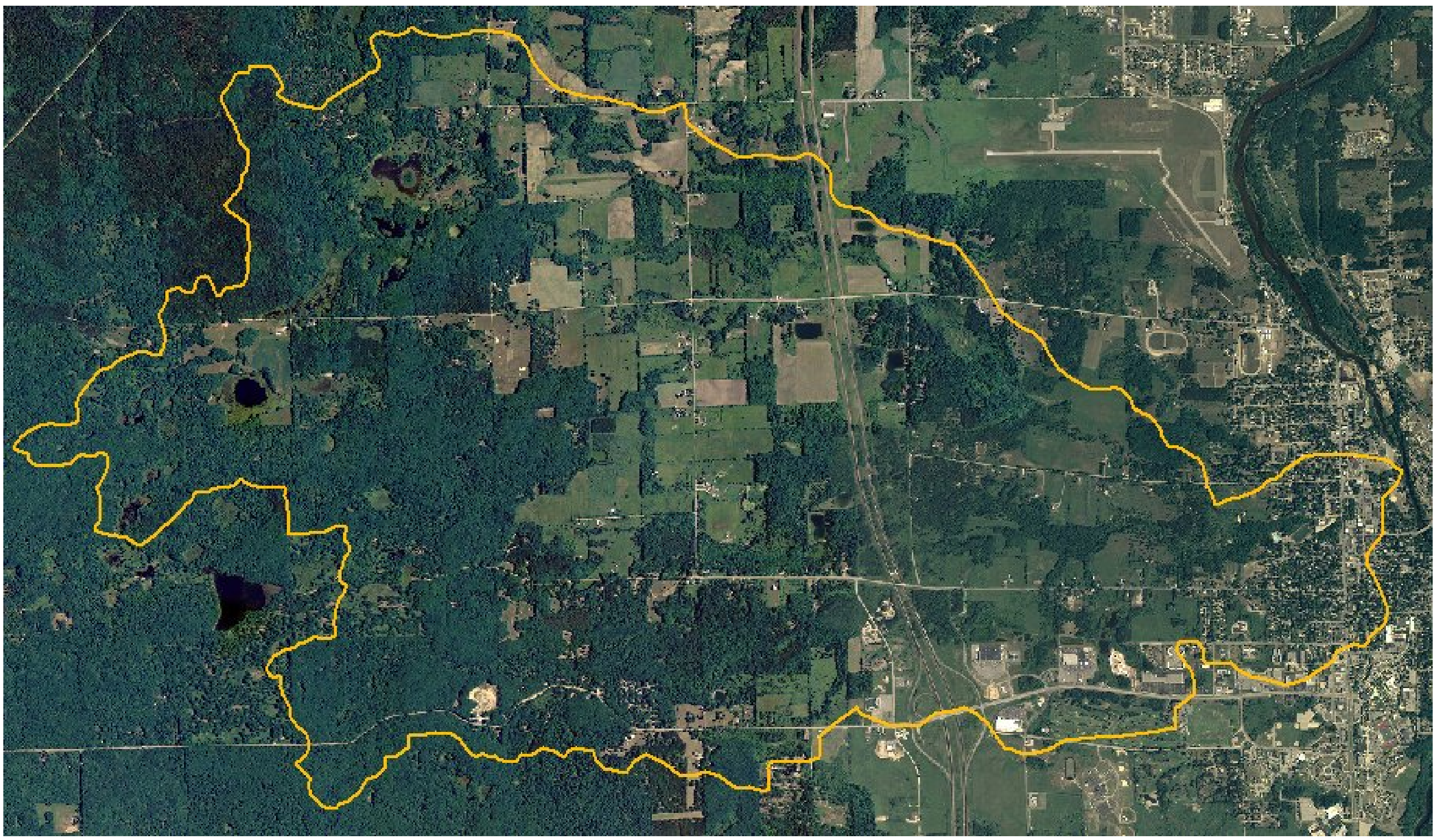
Mitchell Creek Watershed Hydrologic Study



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DEQ
Michigan's Nonpoint Source Program

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This Nonpoint Source (NPS) Pollution Control project has been funded wholly by the United States Environmental Protection Agency through a Part 319 grant to the Michigan Department of Environmental Quality. This study is in support of a NPS grant, 2005-9119, to the Muskegon River Watershed Assembly. The contents of the document do not necessarily reflect the views and policies of the EPA, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use. For more information, go to www.michigan.gov/deqnps.

The cover is a 2005 aerial photo of the Mitchell Creek Watershed.

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DEQ Michigan's Nonpoint Source Program

Summary

This hydrologic study of the Mitchell Creek watershed was conducted by the Hydrologic Studies Unit (HSU) of the Michigan Department of Environmental Quality (MDEQ) to better understand the watershed's hydrologic characteristics and reported continued channel instability subsequent to a Nonpoint Source (NPS) streambank stabilization project, 1999-0037.

The watershed study has three scenarios corresponding to land cover in 1978 and 2006. Scenarios A and B simulate the actual condition of the watershed. Scenario C is hypothetical and is intended only for comparison.

A. 1978 conditions
B. 2006 conditions with a 0.05 cfs/acre release rate for new development
C. 2006 conditions without a 0.05 cfs/acre release rate

General land use trends for the watershed are illustrated in Figure 1. Additional land use information is provided in the Watershed Description section and in Appendix A of this report.

The hydrologic modeling quantifies changes in stormwater runoff from 1978 to 2006 due to these land use changes. The dominant trend is urbanization and increased imperviousness near Big Rapids and Interstate 131. The associated increased runoff is managed by local stormwater ordinance. For more recent developments, runoff from a 50 percent chance (2-year), 24-hour storm event is limited to a maximum release rate of 0.05 cubic feet per second per acre (cfs/acre). Relatively modest, but frequent, storm events, such as the 50 percent chance storm, have more effect on channel form than extreme flood flows. Unless properly managed, increases in runoff from 1- to 2-year storms increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows. Detailed discussion of the results is in the Hydrologic Analysis section of this report.

The modeling indicates that the 0.05 cfs per acre standard in the stormwater management ordinance is helping protect Mitchell Creek and its tributaries from detrimental flow impacts of land use changes. Channel-forming flows near the mouth of Mitchell Creek have been not significantly changed by the addition of rate controlled developments within the watershed. However, refinements to the stormwater ordinance may help better protect smaller tributaries. These refinements could include 24-hour extended detention of runoff from 1-year storms or provision for retention and infiltration of additional stormwater runoff through Low Impact Development (LID) practices.

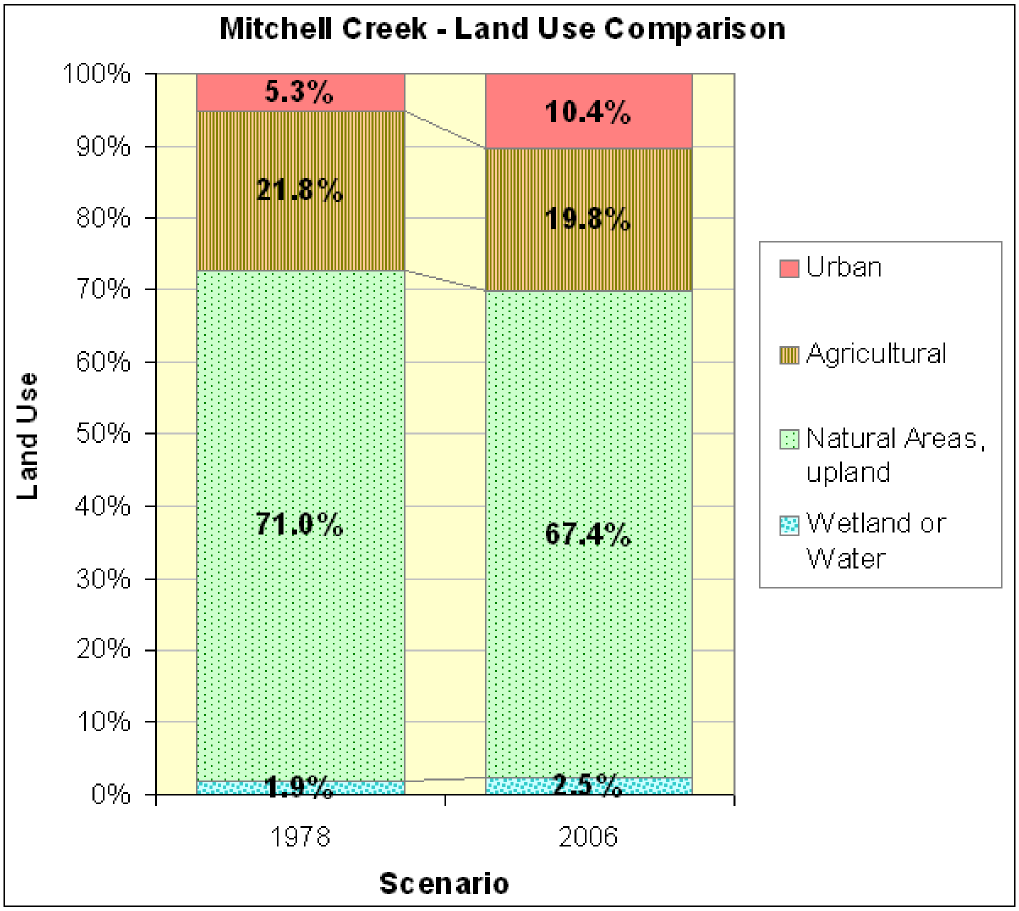

Figure 1: Land Use Comparison, Mitchell Creek Watershed

Watershed Description

The 12.9 square mile Mitchell Creek watershed, Figure 2, outlets to the Muskegon River at Big Rapids and is located in Mecosta and Newaygo Counties. The watershed drainage area to the streambank stabilization project site, located just downstream of Northland Drive, is 12.7 square miles. One 0.6 square mile area of the watershed is defined as non-contributing, meaning it does not contribute surface runoff during flood events.

This study divides the watershed into six subbasins, as shown in Figure 3. The watershed delineation changes in two places, Figure 4, from 1978 to 2006 because of earthwork associated with land use changes. Surface runoff volumes and flows were modeled using HEC-HMS 3.1.0 and the runoff curve number technique. This technique, developed by the Natural Resources Conservation Service (NRCS) in 1954, represents the runoff characteristics from the combination of land use and soil data as a runoff curve number. The technique, as adapted for Michigan, is described in "Computing Flood Discharges For Small Ungaged Watersheds (Sorrell, 2003).

The runoff curve numbers were calculated using Geographic Information Systems (GIS) technology from the digital land use and soil data shown in Figures 5 through 8. The land use map depicting MDEQ GIS data for 1978 is shown in Figure 5. The 2006 land use map, Figure 6, is based on HSU's analysis of 2005 and 2006 aerial photos.

Housing density is a part of the curve number calculations. Based on the aerial photos, average residential lot size for both land use scenarios was specified as 1/3 acre in the vicinity of Big Rapids and 1/2 acre for the rest of the watershed.

The NRCS soils data for the watershed is shown in Figures 7 and 8. Soil hydrogroups range from A to D, with A indicating well-drained, high infiltration soils and D indicating poorly-drained, high runoff soils. Where the soil is given a dual classification, B/D for example, the soil hydrogroup was selected based on land use. In these cases, the soil hydrogroup is specified as D for natural land uses, or the alternate hydrogroup (A, B, or C) for developed land uses. The differences in resolved soil hydrogroups from 1978 to 2006 are minor. The runoff curve numbers, calculated from the soil and land use data, are listed in Appendix B.

The areas that developed since the 1978 scenario and were affected by the 0.05 cfs/acre standard were modeled as separate elements. An impervious area for each of these developed areas was assigned based on the land use GIS data, Figures 5 and 6, and Table 1. The imperviousness values for residential, commercial, and industrial land uses are from the NRCS (NRCS, 1986). The pervious portion of the drainage area was assigned a curve number of 30.

Table 1: Imperviousness Table for Impervious Area Analysis

GIS Class	Description	Imperviousness (percent)
1	Residential	38*
2	Commercial	85
3	Industrial	72
4	Road, Utilities	95
5	Gravel Pits	0
6	Outdoor Recreation	0
7	Cropland	0
8	Orchard	0
9	Pasture	0
10	Openland	0
11	Forests	0
12	Open Water	0
13	Wetland	0

* assumed population density of 250 to 1,000 people per square mile

The time of concentration, which is the time it takes for water to travel from the hydraulically most distant point in the watershed to the design point, was calculated from the USGS quadrangles. The same time of concentration values was used in both land use scenarios. Storage coefficients were set equal to the times of concentration because there is little ponding within the watershed. Parameters are detailed in Appendix B.

The design rainfall value used in this study is 2.27 inches, corresponding to the 50 percent chance (2-year) 24-hour storm, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. This storm was selected because runoff from the 50 percent chance storm can be associated with channel-forming flows.

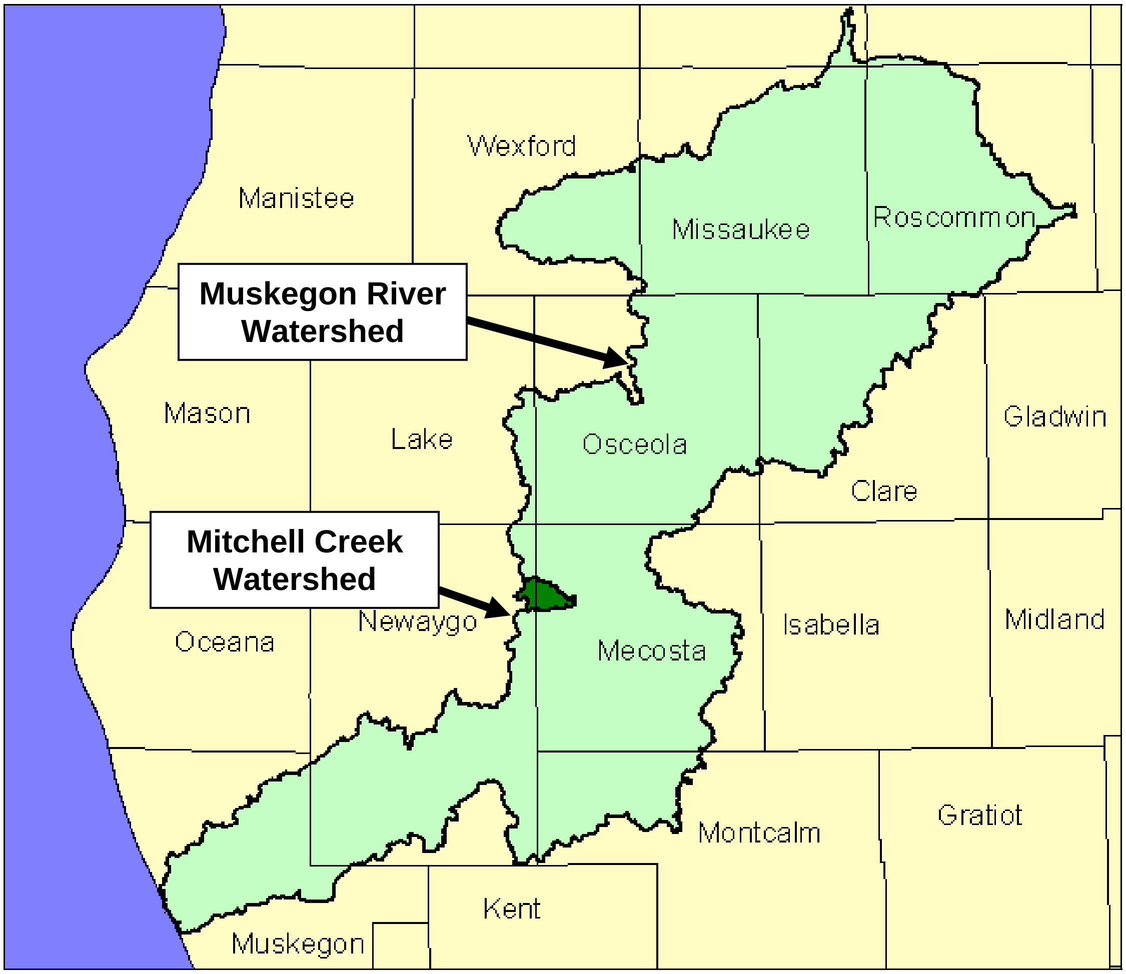

Figure 2: Mitchell Creek Watershed Location

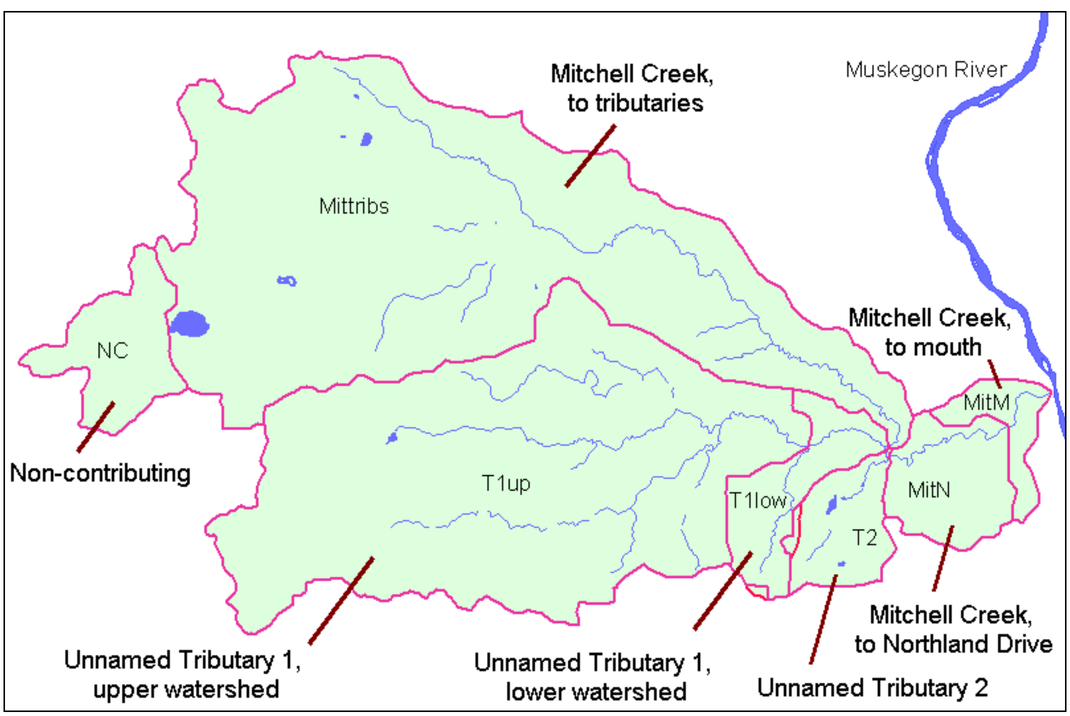

Figure 3: Mitchell Creek Subbasin Identification

Figure 4: Watershed Delineation Changes

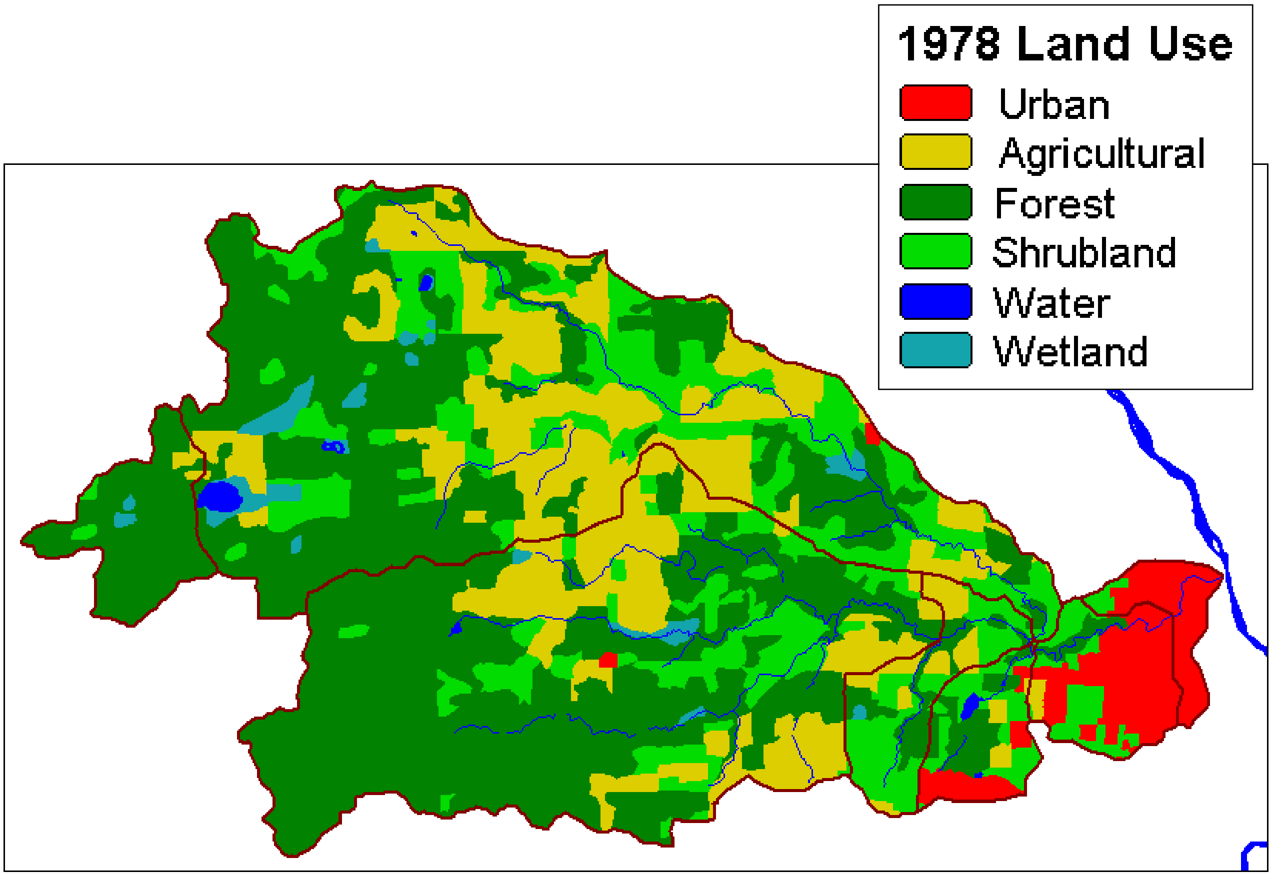

Figure 5: 1978 Land Cover

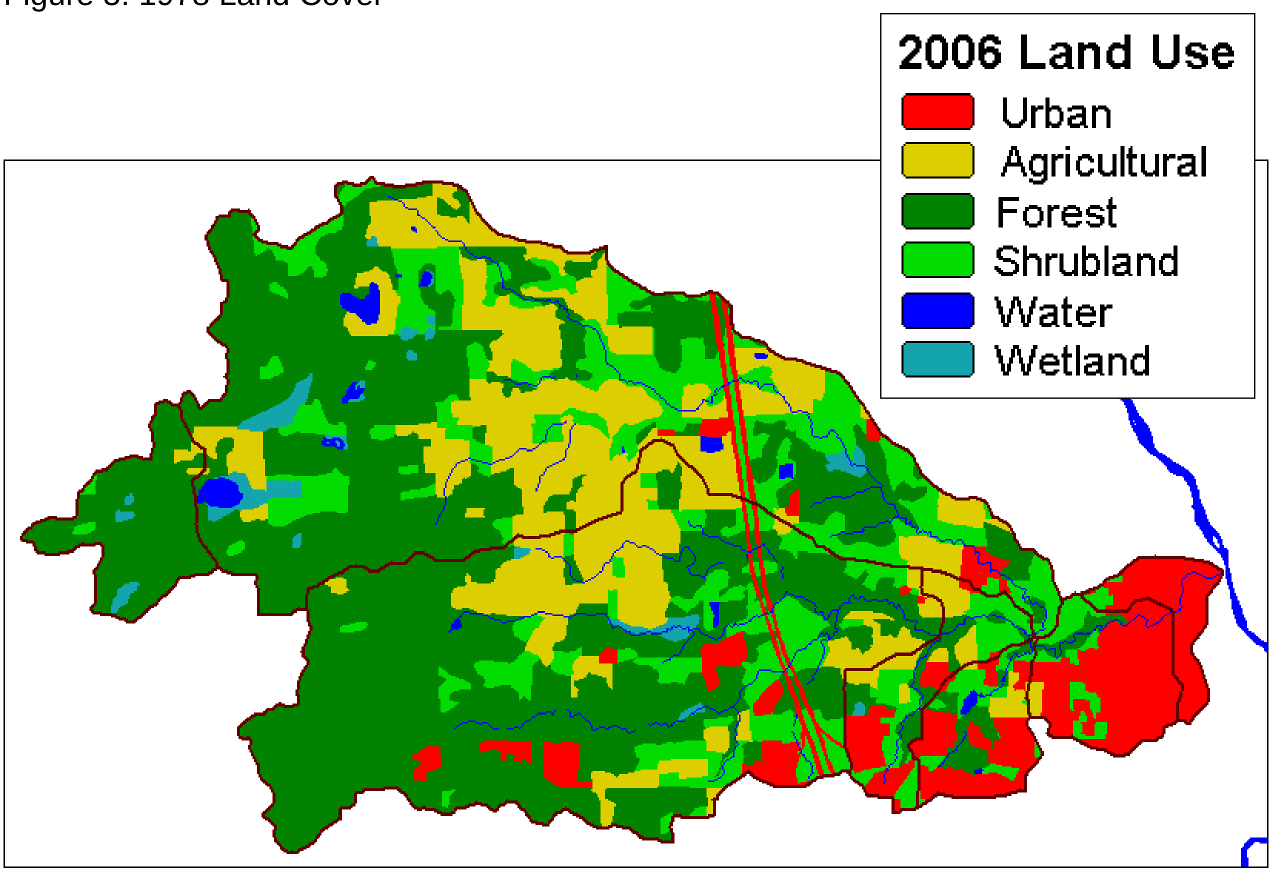

Figure 6: 2006 Land Cover

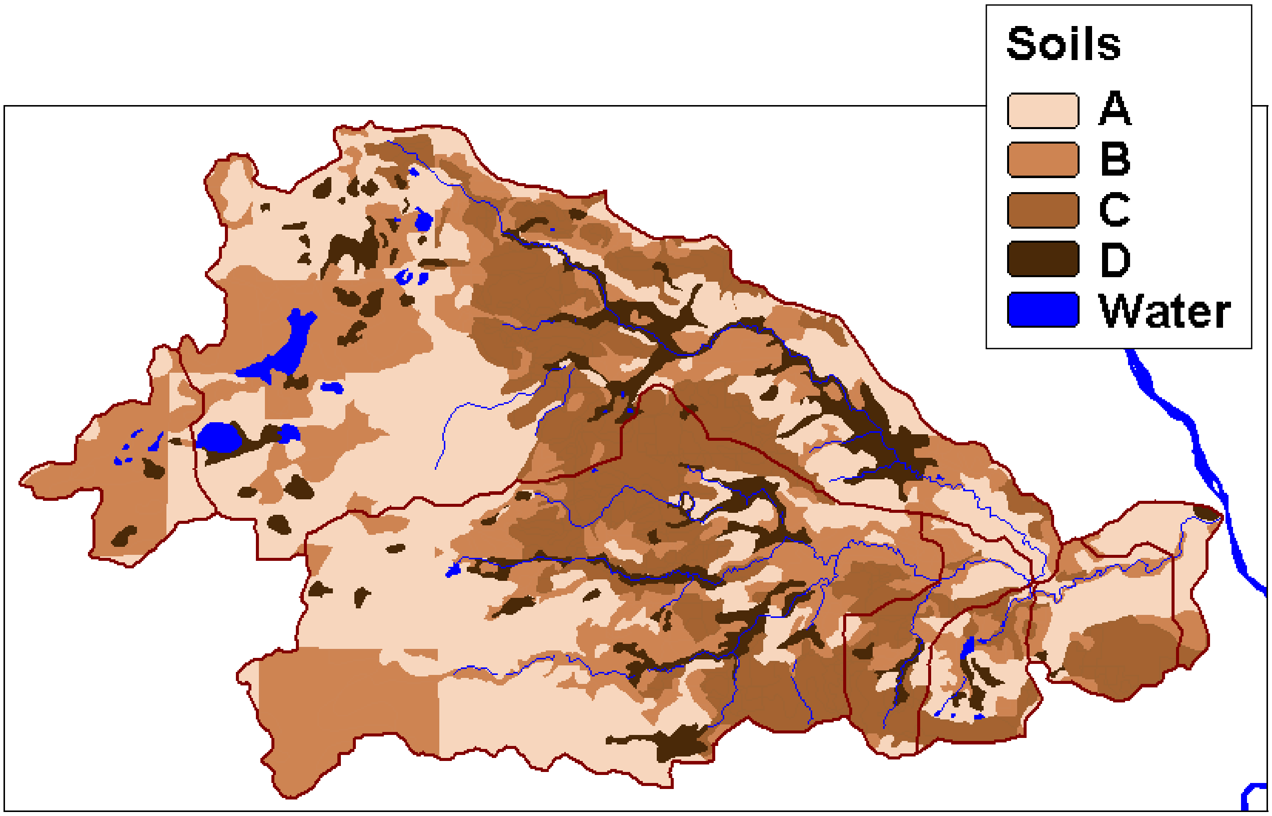

Figure 7: NRCS Soils Data, 1978 Land Use

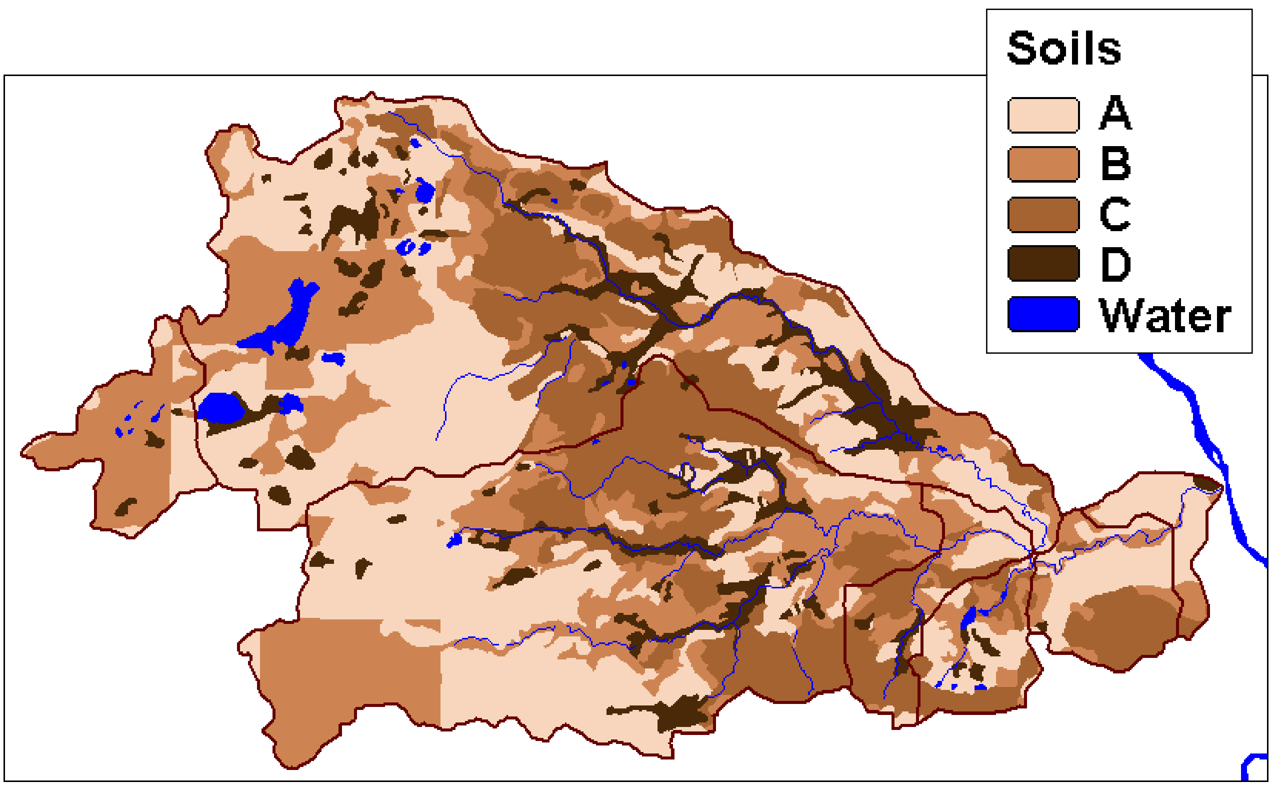

Figure 8: NRCS Soils Data, 2006 Land Use

Hydrologic Analysis

General

The impetus for this study was whether recent hydrologic changes are adversely affecting channel morphology, which is the form and structure of Mitchell Creek and its tributaries. Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. Increases in runoff volumes and peak flows from 1- to 2-year storms increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows. This study is therefore focused on model results from the 50 percent chance (2-year), 24-hour storm. The modeled precipitation event is shown in Figure 9.

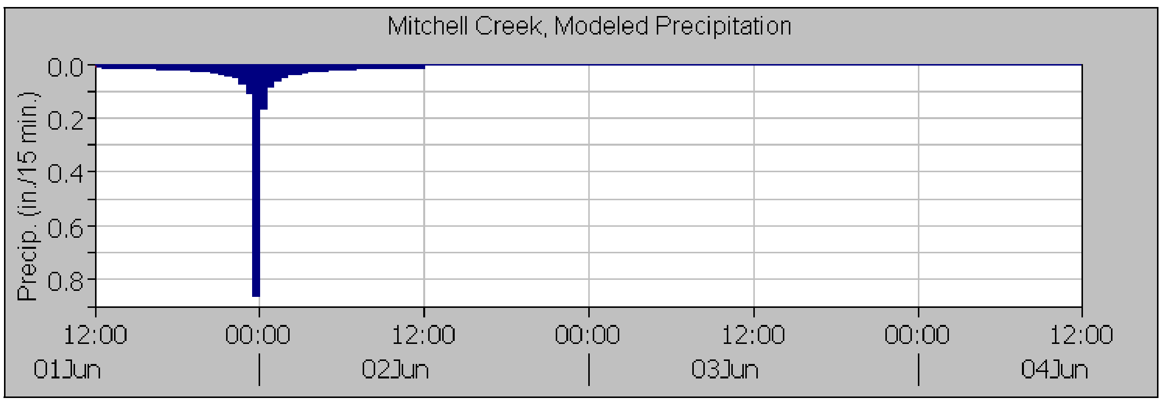

Figure 9: Modeled Precipitation – Precipitation is depicted in 15-minute intervals for clarity

The primary hydrologic change in the watershed since 1978 is urbanization and the associated increased imperviousness near Big Rapids. The addition of Interstate 131 in the 1980’s (Wikipedia, 2007) has focused much of the growth in the area of the watershed with Interstate access. To protect the streams from increased erosion, a local stormwater ordinance mandates that new developments have a maximum release rate of 0.05 cfs/acre for runoff from a 50 percent chance, 24-hour storm event.

The watershed model has three scenarios. Scenarios A and B simulate the actual condition of the watershed. Scenario C is hypothetical and is intended only for comparison.

A. 1978 conditions
B. 2006 conditions with the 0.05 cfs/acre rate control for new development
C. 2006 conditions without the 0.05 cfs/acre rate control

The results indicate that the rate control standard is mitigating effects of the increased runoff. Projected peak flows without the rate control are much higher for Mitchell Creek at the mouth and at the park and for the two unnamed tributaries directly draining the areas recently developed using the rate control standard. Tributary channel capacities would undoubtedly limit the uncontrolled peak flows to something less than projected, but the projected increase does indicate that, without the rate controls, channel-forming flows would have increased markedly and channel erosion would have accelerated. Sound planning and appropriate BMP selection have lessened the flow impacts associated with the increased imperviousness.

Mitchell Creek Results

The effect of hydrologic change in one area of the watershed would normally diminish as the flows move downstream. Both the increasing variety of land uses expected with increasing drainage area and the varied timing of tributary flows adding to the main channel flow as the water flows downstream help attenuate peak flows.

The effect of the additional rate-controlled runoff from recent development in headwater areas of two Mitchell Creek tributaries appears to be minor in Mitchell Creek at its mouth and at Mitchell Creek Park. If a stream gage were installed in either location, the flow changes are likely not measurable above natural variation. Without the rate controls, however, the model predicts much higher peak flows, with the peak flow occurring much earlier than the present peak flow. Tributary channel capacities would undoubtedly limit the uncontrolled peak flows to something less than projected, but the projected increases from both tributaries have similar timing and would likely be measurable. The flashier response and higher flows would likely be destabilizing even in the main channel near the park and mouth.

Figure 10 shows the hydrographs resulting from the 50 percent chance storm at the mouth of Mitchell Creek, its confluence with the Muskegon River. Figure 11 shows the hydrographs resulting from the same storm at Mitchell Creek Park or Northland Drive, 2,500 feet upstream of the mouth.

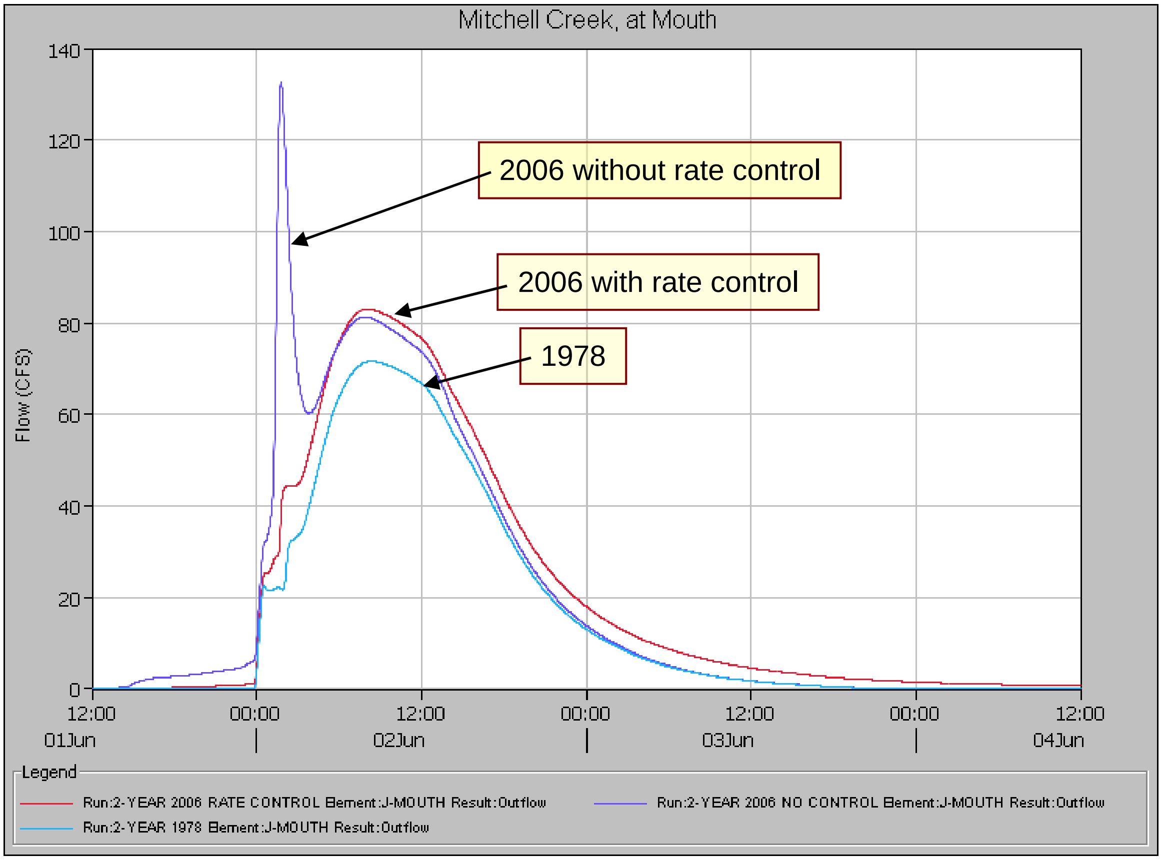

Figure 10: Hydrographs for Mitchell Creek at its mouth

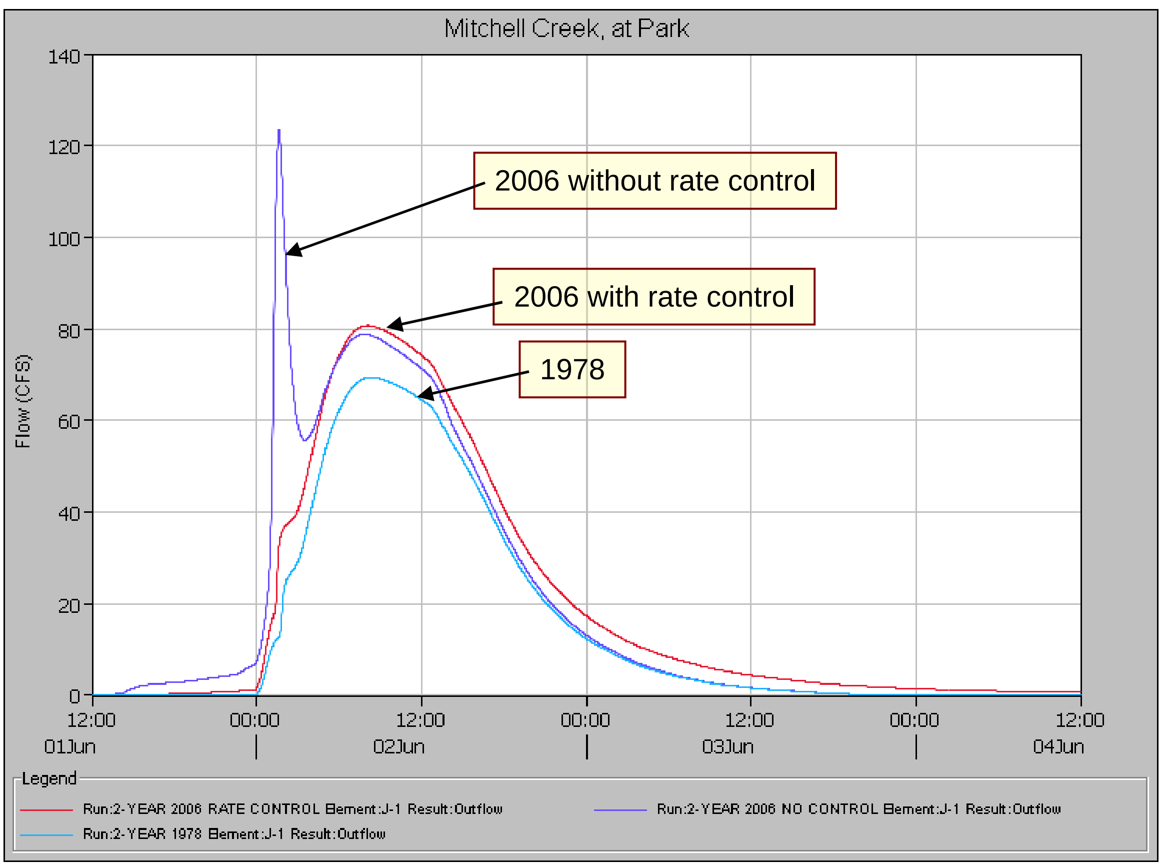

Figure 11: Hydrographs for Mitchell Creek at Northland Drive/Mitchell Creek Park

Tributary 1 Results

Figure 12 shows the hydrographs resulting from the 50 percent chance storm at the mouth of tributary 1, which is its confluence with Mitchell Creek. The model indicates that, from the 1978 scenario to the 2006 rate-controlled scenario, peak flow increased from 33 to 37 cfs and the duration of higher flows is extended slightly. If a stream gage were installed during this period, the overall flow changes may be detectable above natural variation. However, the specific effect of the additional rate-controlled runoff from recent development appears to be minor at the mouth of tributary 1. If a stream gage were installed, flow changes attributable to this portion of the watershed would not likely be discernable above natural variation.

Without the rate controls, the model predicts a much higher peak flow, with the peak flow occurring much earlier than the present peak flow. Tributary channel capacity would undoubtedly limit the uncontrolled flows to something less than projected, but the increased flow would be measurable. The flashier response and higher flows would be destabilizing and cause increased erosion. The contribution of each 2006 scenario model element is further detailed in Figures 13 and 14.

Figure 12 shows, that by attenuating flows from the rate-controlled development, the duration of higher flows is extended slightly. The peak flow increase that occurs 7 hours into day 2 of the model is not primarily the result of the rate-controlled development however. In 1978, the peak flow was 33 cfs and occurred 7 hours into day 2 of the model. Both 2006 scenarios show an increased peak of about 37 cfs at this same time. Because they are similar, and because the peak flow from the upper watershed has increased separately from the recent, rate-controlled developments, this increase is attributed to changes throughout the drainage area. The runoff contribution from the lower watershed is not as readily comparable because the rate-controlled area is modeled separately in the 2006 scenario.

The Stormwater Management, Stream Channel Protection section of this report includes a discussion of 2-year storm peak flow rate control and 24-hour extended detention for runoff from 1-year storms. For this subbasin, rate-controlled detention delays the runoff from the 2-year storm by 18.8 hours, as shown in Figure 15. Applying a 1-year, 24-hour rainfall amount of 1.86 inches to the model, the delay becomes 17.0 hours.

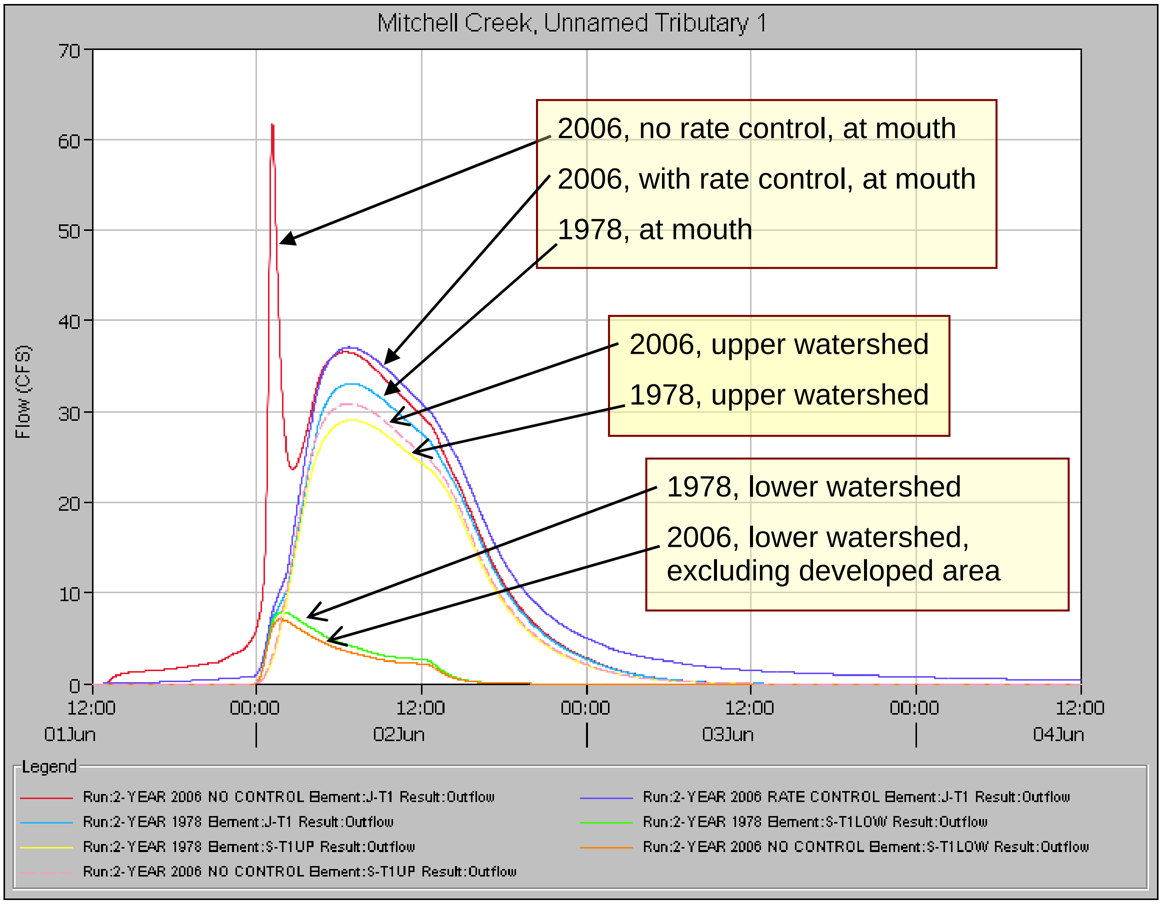

Figure 12: Hydrographs for Unnamed Tributary 1 to Mitchell Creek

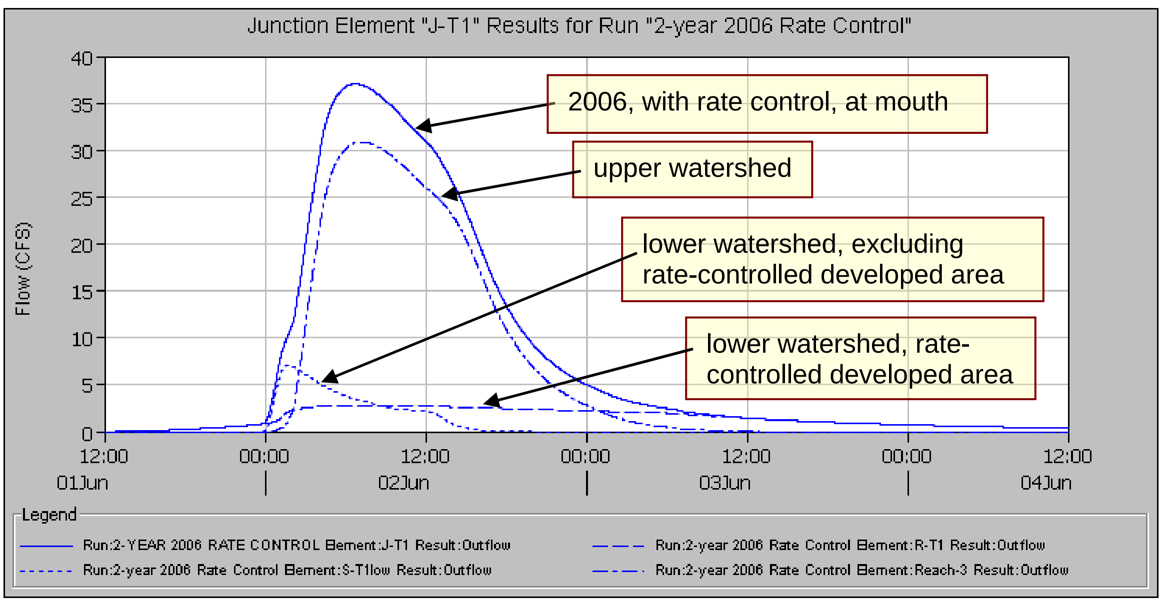

Figure 13: Hydrographs for Unnamed Tributary 1 to Mitchell Creek, 2006 Rate-Controlled

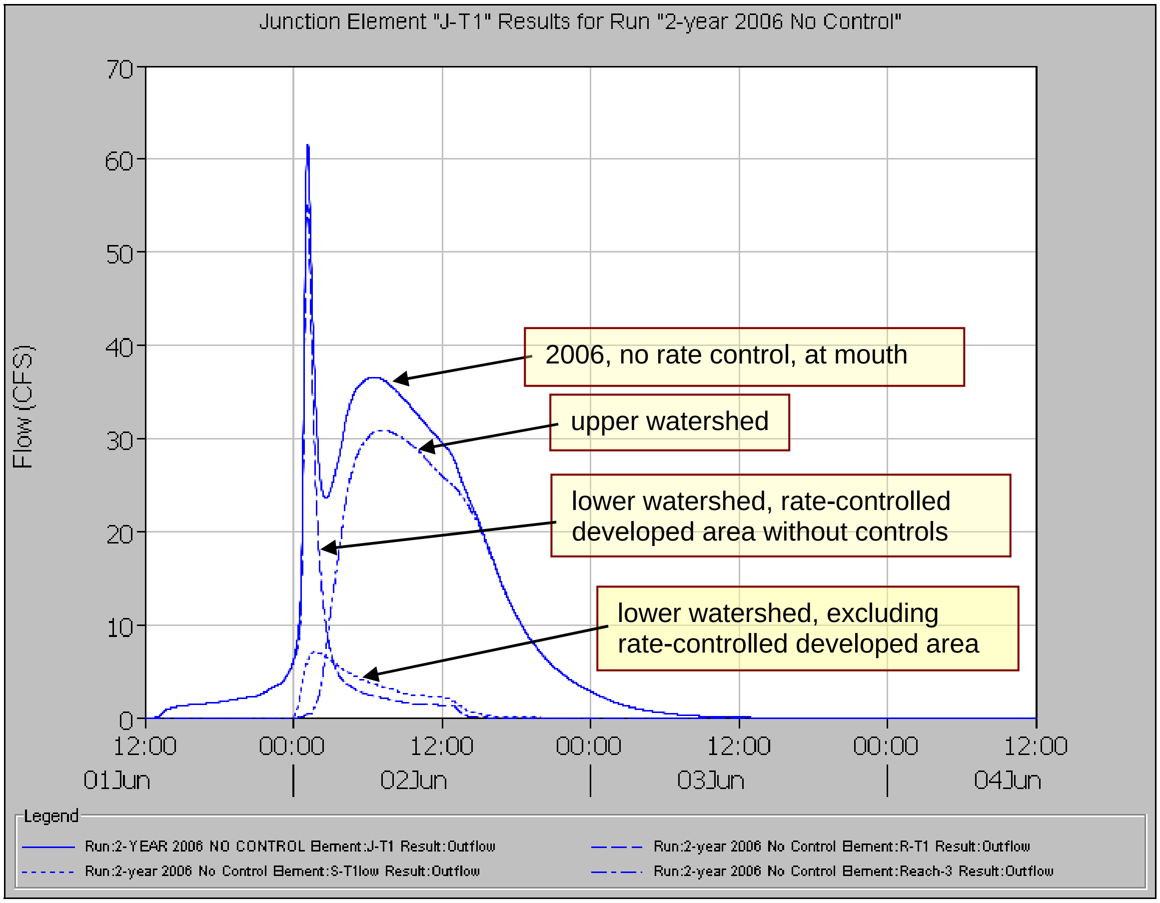

Figure 14: Hydrographs for Unnamed Tributary 1 to Mitchell Creek, 2006 No Rate-Controls

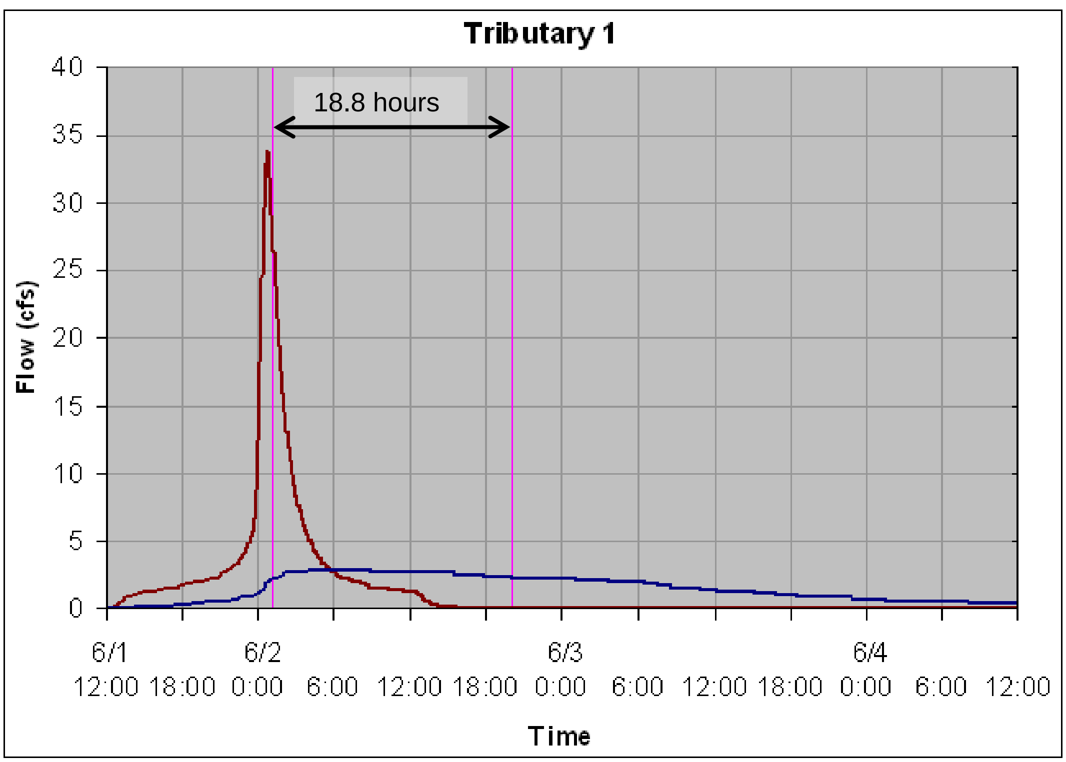

Figure 15: Hydrographs for Unnamed Tributary 1 to Mitchell Creek, 2006, illustrating the change in the hydrographs' centroids

Tributary 2 Results

Figure 16 shows the hydrographs resulting from the 50 percent chance storm at the mouth of tributary 2, which is its confluence with Mitchell Creek. The model indicates that, from the 1978 scenario to the 2006 rate-controlled scenario, peak flow increased from 5 to 12 cfs and the higher flows last longer. If a stream gage were installed during this period, the flow changes should be detectable above natural variation. The effect of the additional rate-controlled runoff from recent development on peak flow appears to be minor at the mouth of tributary 2, although it is contributing to the extended duration of the higher flows. If a stream gage were installed, flow changes attributable to this portion of the watershed may be discernable above natural variation.

Without the rate controls, the model predicts a much higher peak flow, with the peak flow occurring much earlier than the present peak flow. Tributary channel capacity would undoubtedly limit the uncontrolled flows to something less than projected, but the increased flow would be measurable. The flashier response and higher flows would be destabilizing and cause increased erosion. The contribution of each 2006 scenario model element is further detailed in Figures 17 and 18.

Figure 17 shows that the 2006 peak flow is primarily from the non-rate-controlled portion of the watershed. The change in peak flow from 1978 to 2006 shown in Figure 16 is therefore generally not attributable to the rate controlled development. The cause of the extended duration of higher flows, particularly on day 2 of the model, does appear to be caused primarily by the recent, rate-controlled development. However, the extended duration of higher flows occurs in both 2006 scenarios, Figures 17 and 18. This subbasin went from 6 to 34 percent urban land use since 1978. Unless the increased runoff can be infiltrated, extended duration of higher flows is unavoidable. The rate-controlled detention requirement serves to reduce destabilizing peak flows and to reduce at least some of the increased runoff volume to non-erosive velocity.

The Stormwater Management, Stream Channel Protection section of this report includes a discussion of 2-year storm peak flow rate control and 24-hour extended detention for runoff from 1-year storms. For this subbasin, rate-controlled detention delays the runoff from the 2-year storm by 16.4 hours, as shown in Figure 19. Applying a 1-year, 24-hour rainfall amount of 1.86 inches to the model, the delay becomes 15.3 hours.

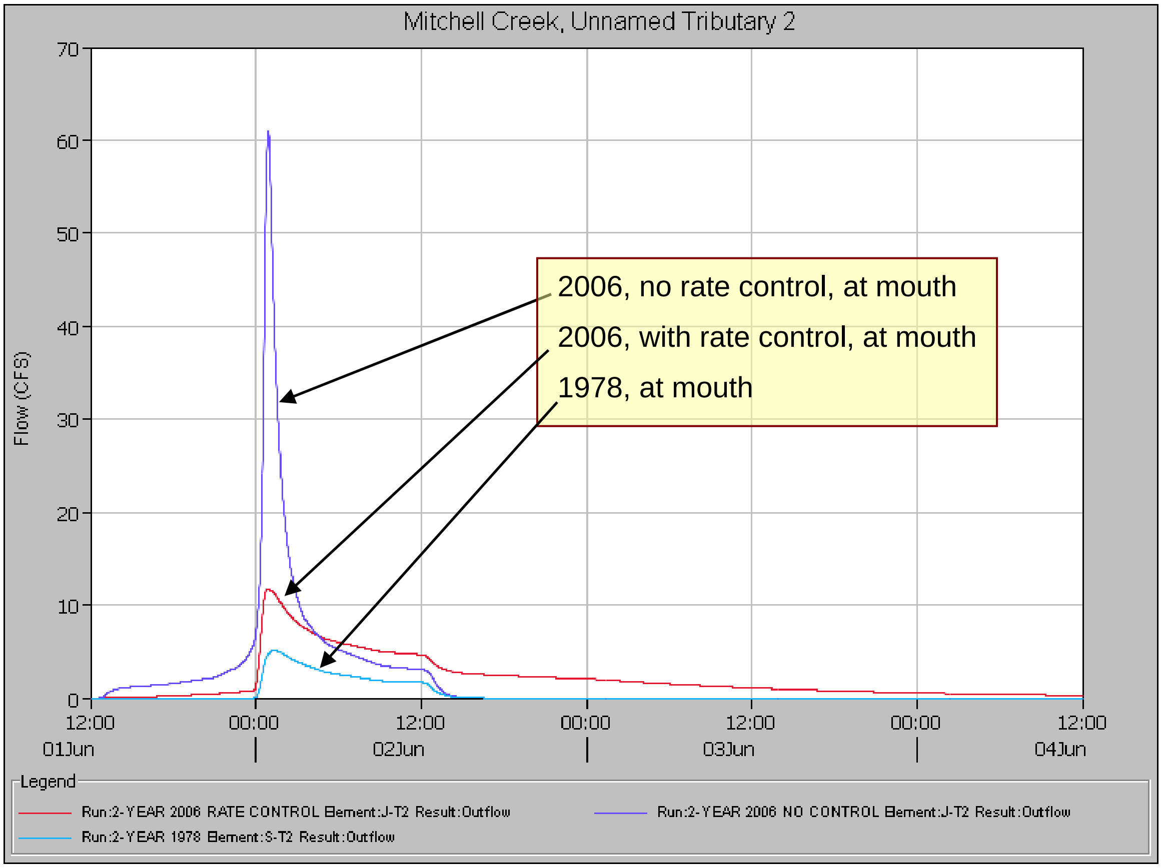

Figure 16: Hydrographs for Unnamed Tributary 1 to Mitchell Creek

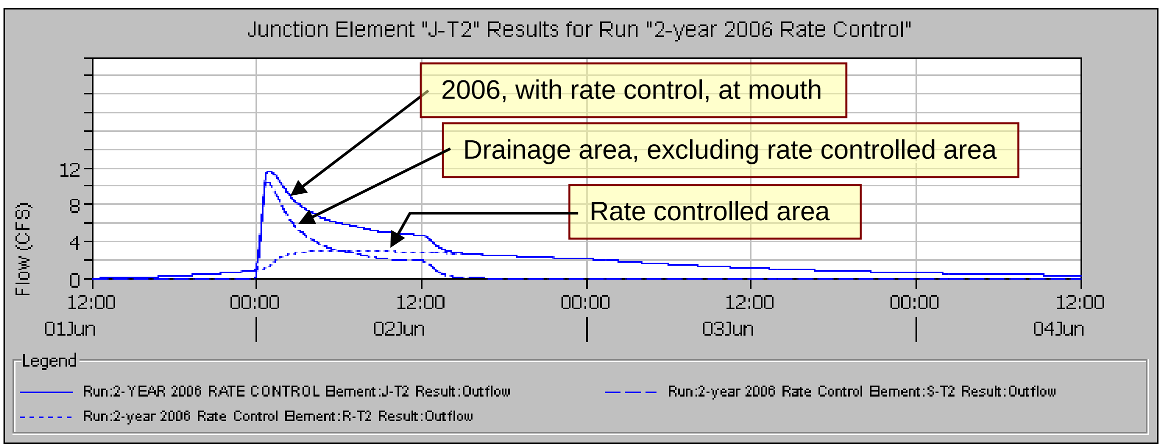

Figure 17: Hydrographs for Unnamed Tributary 1 to Mitchell Creek, 2006 Rate-Controlled

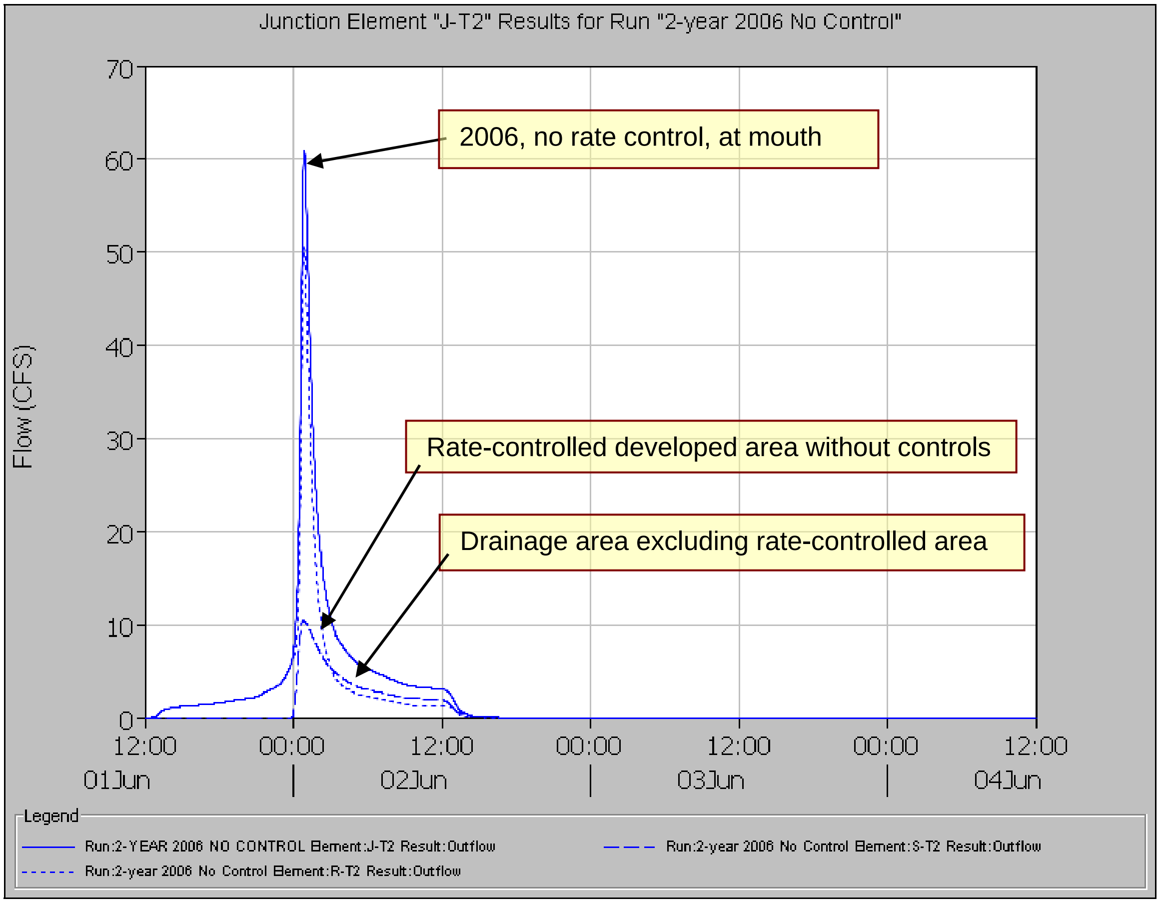

Figure 18: Hydrographs for Unnamed Tributary 1 to Mitchell Creek, 2006 No Rate-Controls

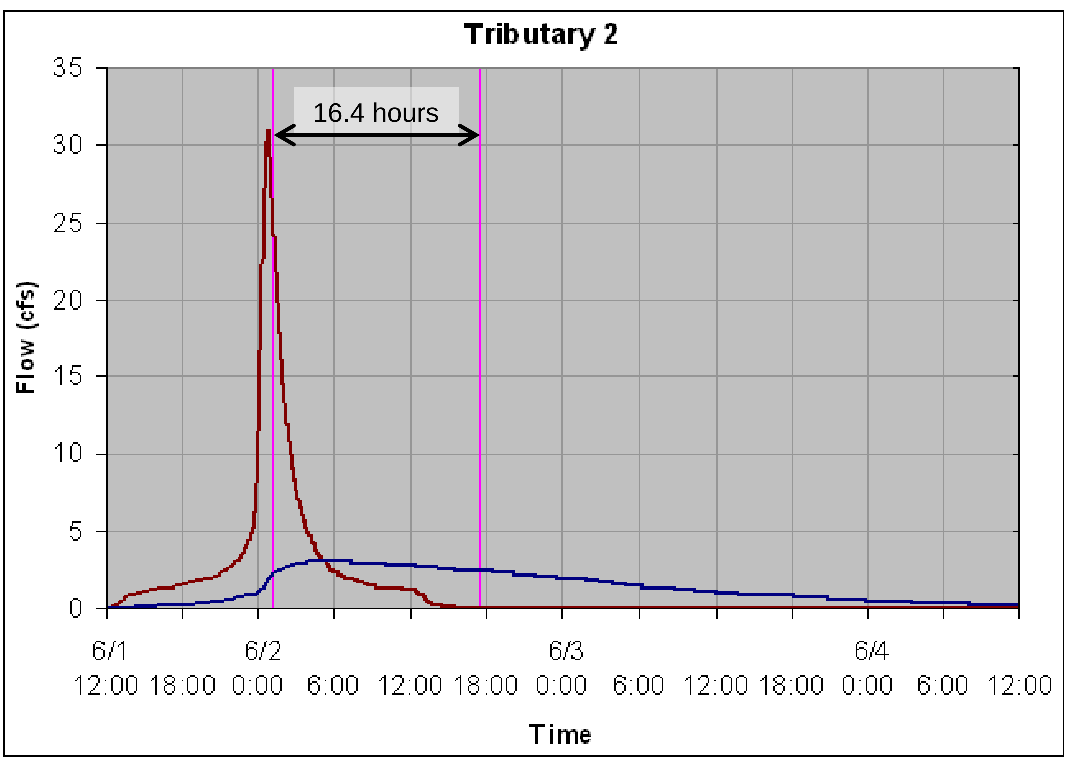

Figure 19: Hydrographs for Unnamed Tributary 2 to Mitchell Creek, 2006, illustrating the change in the hydrographs' centroids

Recommendations

The modeling indicates that the 0.05 cfs per acre standard in the stormwater management ordinance is helping protect Mitchell Creek and its tributaries from harmful flow impacts of land use changes. Channel-forming flows near the mouth of Mitchell Creek have not been significantly changed by the addition of rate controlled developments within the watershed. Other land use changes within the watershed, which either predate the stormwater ordinance or are not covered by it, appear to have more effect on the Mitchell Creek than the rate-controlled developments. However, refinements to the stormwater ordinance may help better protect smaller tributaries. These refinements could include 24-hour extended detention of runoff from 1-year storms or provision for retention and infiltration of additional stormwater runoff through Low Impact Development (LID) practices, as discussed further in the following Stormwater Management, Stream Channel Protection section of this report.

Stormwater Management

When precipitation falls, it can infiltrate into the ground, evapotranspirate back into the air, or run off the ground surface to a water body. It is helpful to consider three principal runoff effects: water quality, channel shape, and flood levels, as shown in Figure 20.

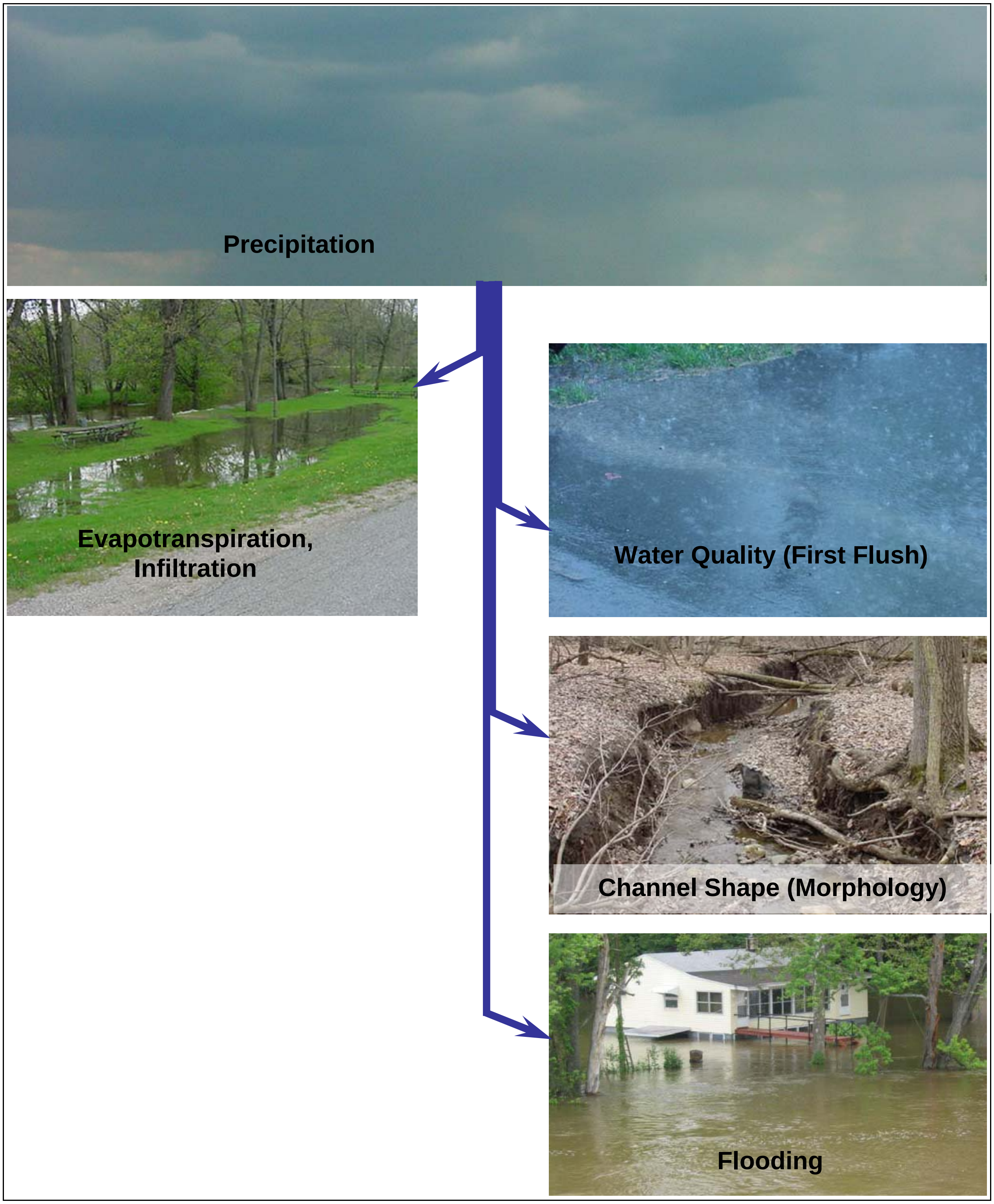

Figure 20: Runoff Impacts

Water Quality

Small runoff events and the first portion of the runoff from larger events typically pick up and deliver the majority of the pollutants to a watercourse in an urban area (Menerey, 1999 and Schueler, 2000). As the rain continues, there are fewer pollutants available to be carried by the runoff, and thus the pollutant concentration becomes lower. Figure 21 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "first-flush." Some of the pollutants can settle out before discharging to a stream if this first flush runoff is detained for a period of time. Filtering systems are also used at some sites to treat the first flush stormwater.

Nationally, the amount of runoff recommended for capture and treatment varies from 0.5 inch per impervious acre to the runoff from a 50 percent chance storm. Michigan BMP guidelines recommend capture and treatment of 0.5 inches of runoff from a single site (Guidebook of Best Management Practices for Michigan Watersheds, 1998). The runoff is then released over 24 to 48 hours or is allowed to infiltrate into the ground within 72 hours. Dry detention ponds are less effective than retention or wet detention ponds, because the accumulated sediment in a dry detention pond may be easily resuspended by the next storm (Schueler, 2000).

Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. For multiple sites or watershed wide design, it is best to design to capture and treat 90 percent of runoff-producing storms. This "90 percent rule" effectively treats storm runoff that could be reaching the treatment at different times during the storm event. It was designed to provide the greatest amount of treatment that is economically feasible. In Michigan, values calculated for these storms range from 0.77 to 1.00 inches. For the Mitchell Creek watershed climatic regions, the calculated value is 0.93 inches. Additional information is available at www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf.

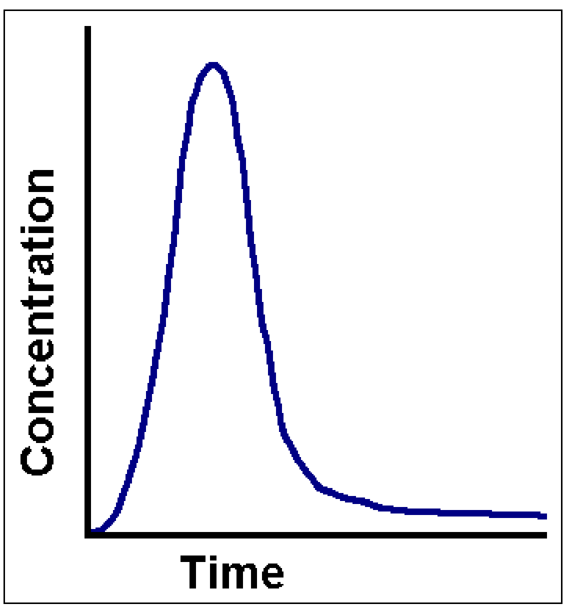

Figure 21: Plot of Pollutant Concentration versus Time

Stream Channel Protection

A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades or degrades. Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural.

Possible causes of erosion are:

- Natural river dynamics
- Sparse vegetative cover due to too much animal or human traffic
- Concentrated runoff adjacent to the streambank, i.e. gullies, seepage
- In-stream flow obstructions, i.e. log jams, failed bridge supports
- An infrequent event, such as an ice jam or low probability flood
- Unusually large or frequent wave action
- A significant change in the hydrologic characteristics (typically land use) of the watershed
- A change in the stream form impacting adjacent portions of the stream, i.e. dredging, channelization

An assessment of the cause(s) of erosion is necessary so that proposed solutions will be permanent and do not simply move the erosion problem to another location. The first six listed causes can produce localized erosion. Either of the last two causes, however, could produce a morphologically unstable stream. Symptoms of active channel enlargement in an unstable stream include:

- Knickpoint migration of the channel bottom
- Extensive and excessive erosion of the stream banks
- Erosion on the inside bank of channel bends
- Evidence in the streambanks of bed erosion down through an armor layer
- Exposed sanitary or storm sewers that were initially installed under the steam bed

Erosion in a morphologically unstable stream is caused by increases in the relatively frequent channel-forming flows that, because of their higher frequency, have more effect on channel form than extreme flood flows. As shown in Figure 22, multiplying the sediment transport rate curve (a) by the storm frequency of occurrence curve (b) yields a curve (c) that, at its peak, indicates the flow that moves most of the sediment in a stream. This flow is termed the effective discharge. The effective discharge usually has a one- to two-year recurrence interval and is the dominant channel-forming flow in a stable stream.

Increases in the frequency, duration, and magnitude of these flows causes stream bank and bed erosion as the stream adapts. According to the *Stream Corridor Restoration* manual, stream channels can often enlarge their cross-sectional area by a factor of 2 to 5 (FISRWG, 10/1998). In *Dynamics of Urban Stream Channel Enlargement, The Practice of Watershed Protection*, ultimate channel enlargement ratios of up to approximately 10 are reported, as shown in Figure 23 (Schueler and Holland, 2000). To prevent or minimize this erosion, watershed stakeholders should specifically consider stormwater management to protect channel morphology. Low impact development and infiltration BMPs can be incorporated to offset flow increases. Stormwater management ordinances can specifically address channel protection. However, where ordinances have included channel protection criteria, it has typically been focused on controlling peak flows from the 2-year storm. The nationally recognized Center for Watershed Protection asserts that 24-hour extended detention for runoff from 1-year storms better protects channel morphology than 2-year peak discharge control because it does not reduce the frequency of erosive bankfull and sub-bankfull flows that often increase as development occurs within the watershed. Indeed, it may actually increase the duration of these erosive, channel-forming flows. The intent of 24-hour extended detention for runoff from 1-year storms is to limit detention pond outflows from these storms to non-erosive velocities, as shown in Figure 24. A few watershed plans funded through the MDEQ Nonpoint Source Program have recommended requirements based on this criterion. One such example is from the Anchor Bay Technical Report and is shown in Figure 25. This analysis, which is for climatic region 10, is for 2.06 inches of rainfall. The Mitchell Creek watershed is mostly in climatic region 6, which has a 50 percent chance (2-year) 24-hour storm design rainfall value of 2.27 inches, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. The MDEQ Nonpoint Source Program is exploring funding this analysis for Michigan. The results would be provided to the Mitchell Creek stakeholders when available.

Control of channel-forming flows is not essential for some drainage areas. For example, detention designed to prevent streambank erosion may not be needed for runoff routed from a city through storm sewers to a large river, simply because the runoff routed through the storm sewers enters the river well ahead of the peak flow in the river. In this case, the city's management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as water quality improvement, groundwater replenishment, or if watershed planning indicates continued regional development would alter the river's flow regime or increase flood levels.

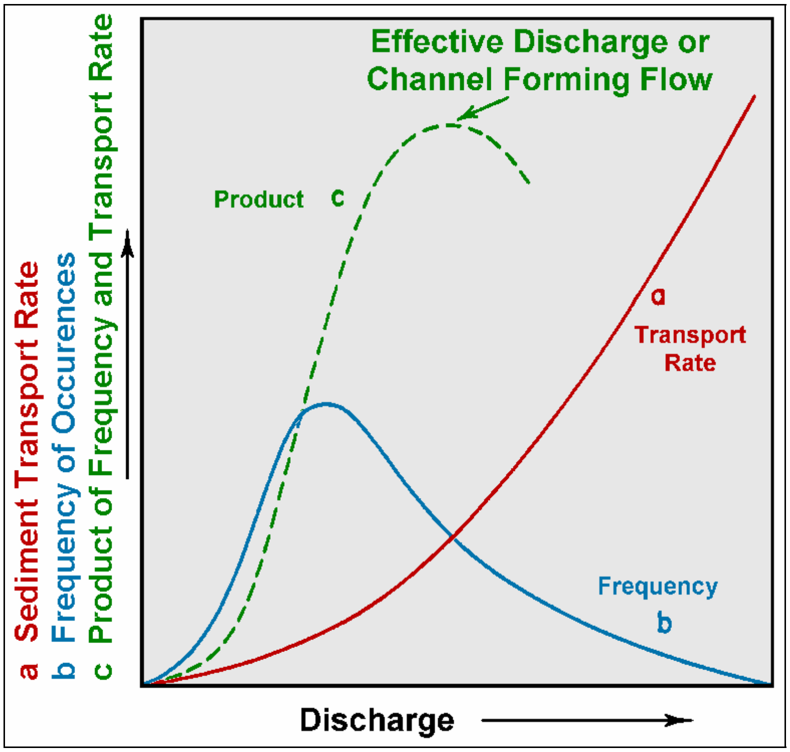

Figure 22: Effective Discharge (from *Applied River Morphology*. 1996. Dave Rosgen)

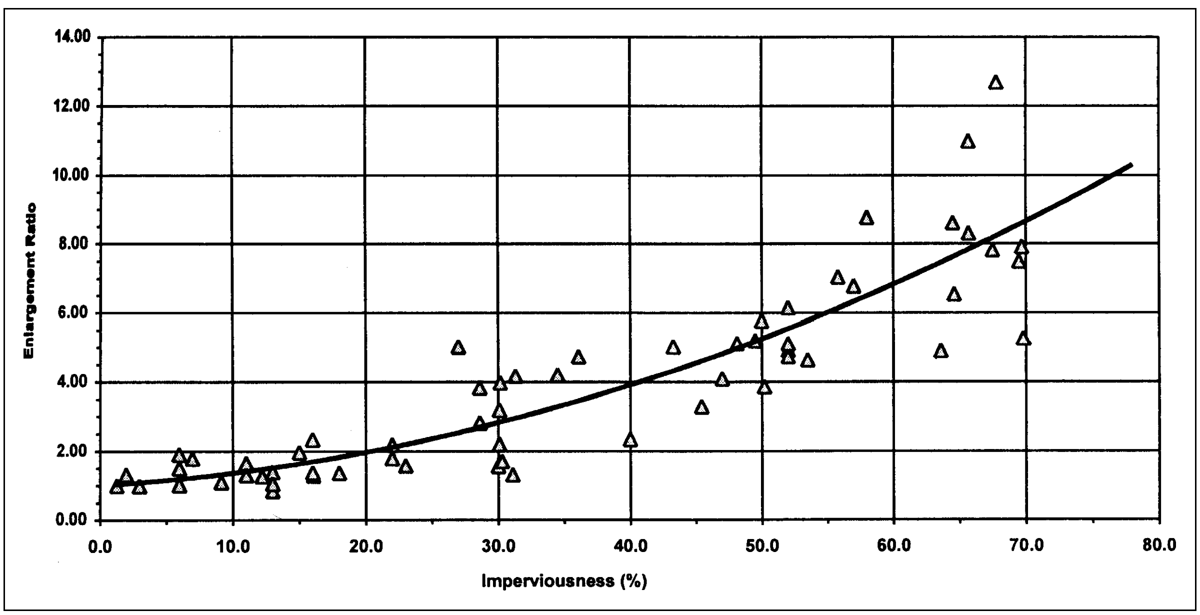

Figure 23: "Ultimate" Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From *The Practice of Watershed Protection*, Thomas R. Schueler and Heather K. Holland, 2000)

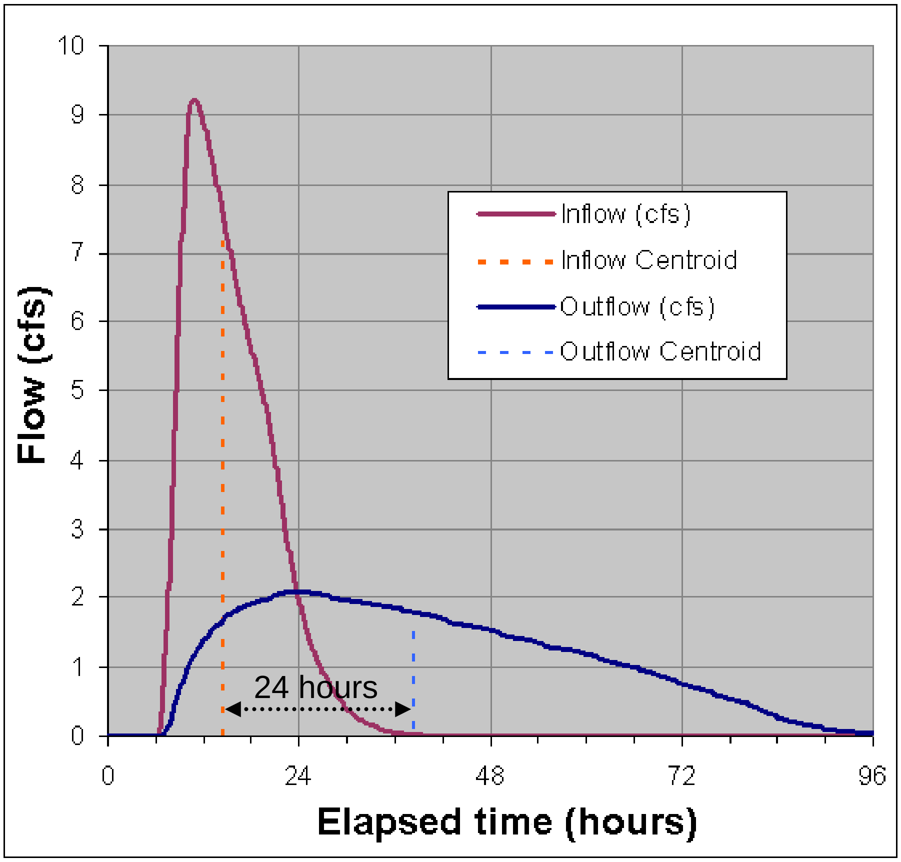

Figure 24: Example of 24-hour extended detention criterion applied to detention pond design

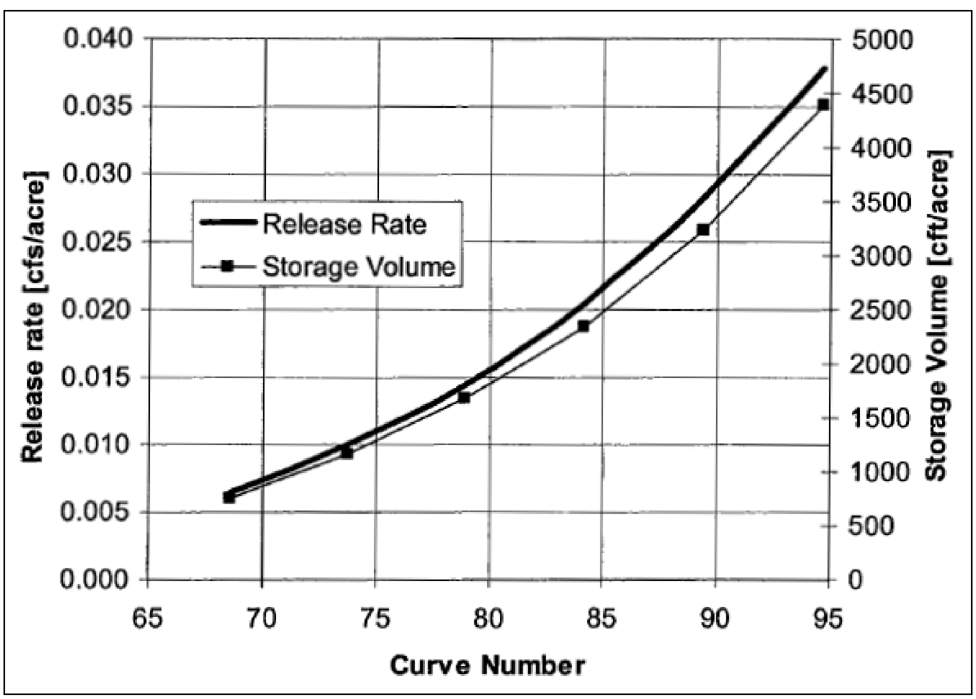

Figure 25: Example of detention pond requirements derived from the 24-hour extended detention criterion

Flood Protection

A river, stream, lake, or drain may occasionally overflow its banks and inundate adjacent land. This land is the floodplain. The floodplain refers to the land inundated by the 1 percent chance flood, commonly called the 100-year flood. Typically, a stable stream will recover naturally from these infrequent events. Developments should always include stormwater controls that prevent flood flows from exceeding pre-development conditions and putting people, homes, and other structures at risk. Many localities require new development to control the 4 percent chance flood, commonly called the 25-year flood, with some adding requirements to control the 1 percent chance flood.

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Appendix A: Mitchell Creek Hydrologic Analysis Data

The following tables summarize the results of the hydrologic analysis by subbasin. Table A1 presents land use information. Table A2 provides runoff volumes and peak flood flows per subbasin. Table A3 provides in-stream runoff volumes and peak flood flows.

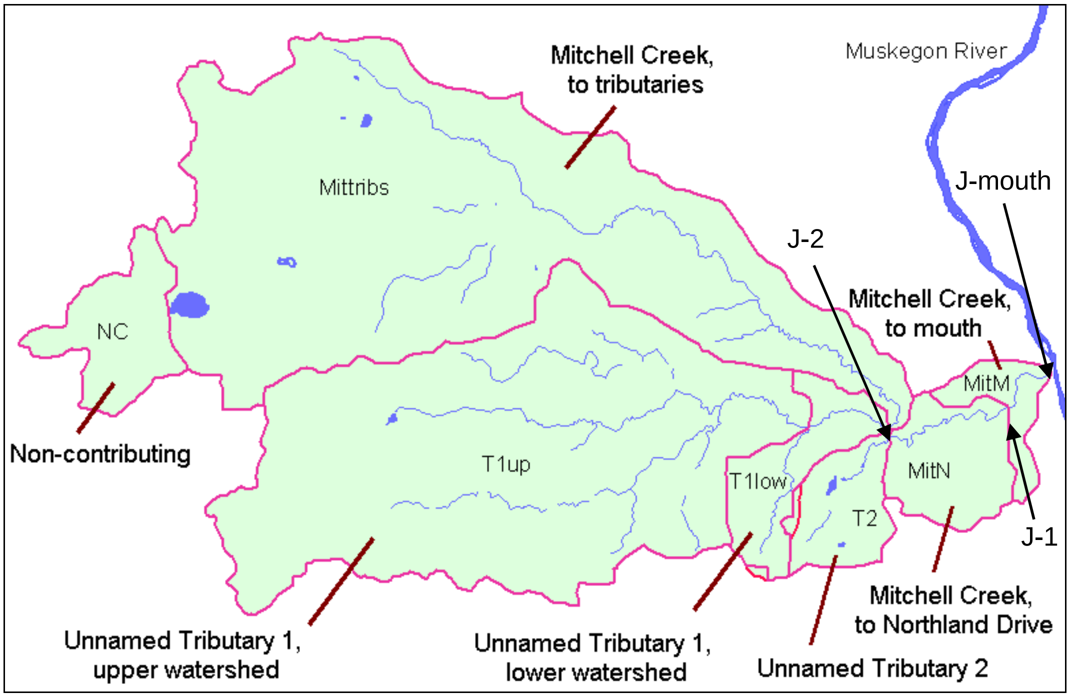

Figure A-1: Watershed Overview with Hydrologic Elements labeled

Table A1: Land Use by Subbasins

Description	Scenario	Residential	Institutional	Utilities	Gravel Pit	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland
Mittribs	1978					0.1%	25.3%	0.6%	1.8%	23.5%	45.4%		3.2%
	2006	1.2%		0.8%		0.1%	24.2%	0.1%	2.4%	22.2%	44.9%	1.2%	2.9%
T1up	1978	0.2%					18.9%		2.3%	13.7%	64.2%		0.8%
	2006	2.5%	1.4%	1.1%	0.4%		15.2%		2.0%	15.2%	61.4%	0.1%	0.8%
T1low	1978					0.1%	23.5%		0.1%	51.4%	24.0%		1.0%
	2006	3.3%	19.9%	0.5%			20.7%		0.1%	33.0%	21.5%		1.1%
T2	1978	5.9%				18.0%	4.0%	3.0%		35.3%	32.0%	1.8%	
	2006	13.8%	19.9%			17.3%	8.9%			18.4%	19.9%	1.7%	
MitN	1978	54.1%	6.1%			4.3%	3.2%			24.7%	7.5%		
	2006	54.9%	14.5%			4.3%	2.9%			15.8%	7.5%		
MitM	1978	50.1%	41.3%							8.6%			
	2006	51.4%	41.3%							7.3%			
NC	1978						2.7%			2.4%	93.2%		1.7%
	2006						2.6%			2.3%	89.6%		5.4%
Entire Watershed	1978	3.4%	1.0%			0.8%	19.8%	0.4%	1.6%	20.2%	50.8%	0.1%	1.9%
	2006	5.3%	3.3%	0.8%	0.1%	0.8%	17.9%		1.8%	18.5%	48.9%	0.6%	1.9%

Table A2: Runoff Volume and Peak flow by Subbasin

ID	Subbasin Description	Scenario	Area (sq. mi.)	Peak Flow (cfs)	Total Runoff (acre-feet)
Mittribs	Mitchell Creek to confluence with tributaries 1 and 2	1978	5.81	32	43.5
		2006	5.81	35	47.7
T1up	Tributary 1, upper watershed	1978	4.78	29	32.5
		2006	4.78	31	34.4
T1low	Tributary 1, lower watershed	1978	0.54	8	5.0
		2006	0.42	7	4.2
T1lowimp	Tributary 1, lower watershed development	2006 NC	0.09	55	9.3
		2006 RC	0.09	3	8.7
T2	Tributary 2	1978	0.41	5	2.9
		2006	0.33	10	4.1
T2imp	Tributary 2, development	2006 NC	0.09	51	8.5
		2006 RC	0.09	3	8.1
MitN	Mitchell to Northland	1978	0.54	12	6.6
		2006	0.54	16	8.3
MitM	Mitchell to mouth	1978	0.24	22	5.2
		2006	0.24	23	5.3

Table A3: In-Stream Runoff Volume and Peak flow

ID	Creek Location Description	Scenario	Area (sq. mi.)	Peak Flow (cfs)	Total Runoff (acre-feet)
J-2	Mitchell Creek below confluence with tributaries 1 and 2	1978	11.54	65	83.9
		2006 NC	11.52	114	108.2
		2006 RC	11.52	76	107.2
J-1	Mitchell Creek at Mitchell Creek Park/Northland Drive	1978	12.08	69	90.5
		2006 NC	12.06	124	116.4
		2006 RC	12.06	81	115.4
J-mouth	Mitchell Creek at mouth	1978	12.32	72	95.7
		2006 NC	12.30	133	121.7
		2006 RC	12.30	83	120.7

Appendix B: Mitchell Creek Hydrologic Parameters

The watershed was modeled using HEC-HMS 3.1.0 to calculate surface runoff volumes and peak flows from individual subbasins. This appendix is provided so that the model may be recreated.

Table B1 provides the hydrologic parameters that were specified for each of the subbasin elements in the HEC-HMS model, Figures B-1 and B-2. The storage coefficient for each subbasin was set equal to the associated time of concentration. Where the percent impervious fields are blank, imperviousness is incorporated in the curve numbers. The initial loss fields in the HEC-HMS model were left blank so that the model uses the standard equation based on the curve number.

Table B2 provides the hydrologic parameters that were specified for the reservoirs that simulate the 0.05 cfs/acre rate control specified in the local stormwater ordinance.

Table B3 provides the hydrologic parameters that were specified for the reach routing.

The HEC-HMS model was run for a three-day duration using a one-minute computation interval.

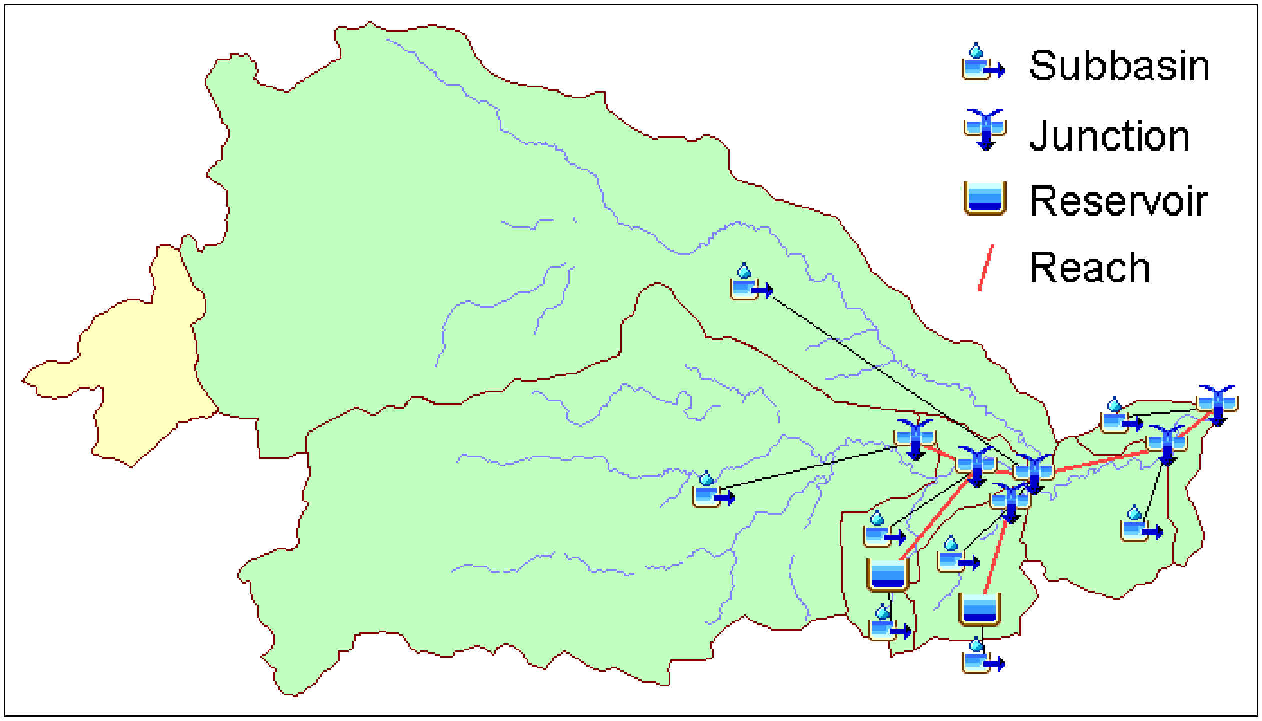

Figure B-1: HMS Hydrologic Model Overview

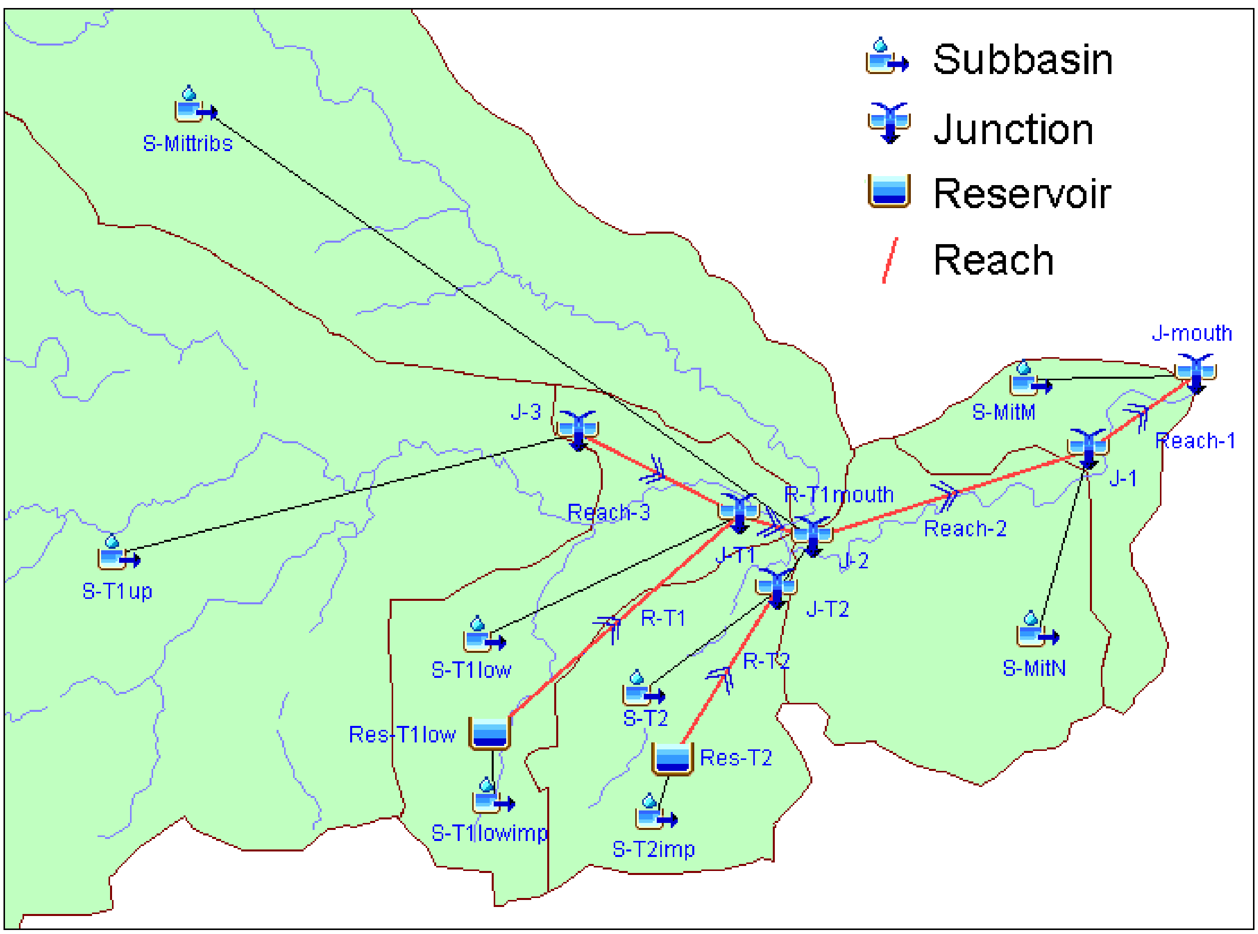

Figure B-2: HMS Hydrologic Model Elements with labels

Table B1: Subbasin Parameters – Drainage Area and Curve Number

Subbasin	Scenario	Drainage Area (sq. mi.)	Curve Number	Impervious Percent	Time of Concentration	Storage Coefficient
Mittribs	1978	5.81	61.4		6.57	6.57
	2006	5.81	62.1			
T1up	1978	4.78	60.7		4.14	4.14
	2006	4.78	61.1			
T1low	1978	0.54	63.0		1.36	1.36
	2006	0.42	63.8			
T1lowimp	2006	0.09	30	85%	1.00	1.00
T2	1978	0.41	61.0		0.79	0.79
	2006	0.33	65.7			
T2imp	2006	0.09	30	78%	1.00	1.00
MitN	1978	0.54	65.5		0.79	0.79
	2006	0.54	67.8			
MitM	1978	0.24	71.8		0.61	0.61
	2006	0.24	72.0			

Table B2: Reservoir Storage Parameters

Reservoir	Storage (acre-feet)	Discharge (cfs)
T-1low	0.0	0.0
	3.0	2.0
	6.7	2.8
T-2	0.0	0.0
	3.0	2.0
	6.0	3.0

Table B2: Reach Routing Parameters

Reach	Method	Cross-section: Station (ft.), Elevation (ft.)	Length	Slope (ft/ft)	Manning's n
Reach-1	Muskingum-Cunge, 8-point	0.0, 4.5; 12.7, 3.1; 17.9, 0.9; 21.5, 0.0; 26.5, 0.0; 32.7, 0.4; 37.0, 3.3; 40.0, 4.4	2475	0.005	0.06 channel, 0.07 overbank
Reach-2	Muskingum-Cunge, 8-point	0.0, 4.5; 12.7, 3.1; 17.9, 0.9; 21.5, 0.0; 26.5, 0.0; 32.7, 0.4; 37.0, 3.3; 40.0, 4.4	6052	0.003	0.06 channel, 0.07 overbank
Reach-3	Muskingum-Cunge, 8-point	0.0, 3.2; 14.8, 2.2; 15.6, 0.3; 16.8, 0.1; 22.9, 0.0; 24.6, 0.3; 26.2, 3.0; 33.0, 3.2	3405	0.004	0.07 channel, 0.10 overbank
Reach	**Method**	**Lag (minutes)**	**Comments**		
R-T1	Lag	51			
R-T2	Lag	36			
R-TImouth	Lag	1	This reach was added to enhance graphical output.		

Appendix C: Glossary

Aggrade - to fill and raise the level of a stream bed by deposition of sediment.

Alluvium - sediment deposited by flowing rivers and consisting of sands and gravels.

Bankfull discharge - that discharge of stream water that just begins to overflow in the active floodplain. The active floodplain is defined as a flat area adjacent to the channel constructed by the river and overflowed by the river at recurrence interval of about 2 years or less. Erosion, sediment transport, and bar building by deposition are most active at discharges near bankfull. The effectiveness of higher flows, called over bank or flood flows, does not increase proportionally to their volume above bankfull in a stable stream, because overflow into the floodplain distributes the energy of the stream over a greater area. See also channel-forming and effective discharge.

Base Flow - the part of stream flow that is attributable to long-term discharge of groundwater to the stream. This part of stream flow is not attributable to short-term surface runoff, precipitation, or snow melt events.

Best Management Practice (BMP) - structural, vegetative, or managerial practices used to protect and improve our surface waters and groundwaters.

Channel-forming Discharge - a theoretical discharge which would result in a channel morphology close to the existing channel. See also effective and bankfull discharge.

Critical Areas - the geographic portions of the watershed contributing the majority of the pollutants and having significant impacts on the waterbody.

Critical Depth - depth of water for which specific energy is a minimum.

Curve Number - see Runoff Curve Number.

Design Flow - projected flow through a watercourse which will recur with a stated frequency. The projected flow for a given frequency is calculated using statistical analysis of peak flow data or using hydrologic analysis techniques.

Detention - practices which store stormwater for some period of time before releasing it to a surface waterbody. See also retention.

Dimensionless Hydrograph - a general hydrograph developed from many unit hydrographs, used in the Soil Conservation Service method.

Direct Runoff Hydrograph - graph of direct runoff (rainfall minus losses) versus time.

Discharge - volume of water moving down a channel per unit time. See also channel-forming, effective, and bankfull discharge.

Drainage Divide - boundary that separates subbasin areas according to direction of runoff.

Effective Discharge - the calculated measure of channel forming discharge. This calculation requires long-term water and sediment measurements, although modeling results are sometimes substituted. See also channel-forming and bankfull discharge.

Ephemeral Stream - a stream that flows only during or immediately after periods of precipitation. See also intermittent and perennial streams.

Evapotranspiration - the combined process of evaporation and transpiration.

First Flush - the first part of a rainstorm that washes off the majority of pollutants from a site. The concept of first flush treatment applies only to a single site, even if just a few acres, because of timing of the runoff. Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet.

Flashiness - has no set definition but is associated with the rate of change of flow. Flashy streams have more rapid flow changes.

Flood Hazard Zone - area that will flood with a given probability.

Groundwater - that part of the subsurface water that is in the saturated zone.

Headwater Stream - the system of wetlands, swales, and small channels that mark the beginnings of most watersheds.

Hydraulic Analysis - an evaluation of water elevation for a given flow based on channel attributes such as slope, cross-section, and vegetation.

Hydrograph - graph of discharge versus time.

Hydrologic Analysis - an evaluation of the relationship between stream flow and the various components of the hydrologic cycle. The study can be as simple as determining the watershed size and average stream flow, or as complicated as developing a computer model to determine the relationship between peak flows and watershed characteristics, such as land use, soil type, slope, rainfall amounts, detention areas, and watershed size.

Hydrologic Cycle - When precipitation falls to the earth, it may:

- be intercepted by vegetation, never reaching the ground.
- infiltrate into the ground, be taken up by vegetation, and evapotranspirated back to the atmosphere.
- enter the groundwater system and eventually flow back to a surface water body.
- runoff over the ground surface, filling in depressions.
- enter directly into a surface waterbody, such as a lake, stream, or ocean.

When water evaporates from lakes, streams, and oceans and is re-introduced to the atmosphere, the hydrologic cycle starts over again.

Hydrology - the occurrence, distribution, and movement of water both on and under the earth's surface. It can be described as the study of the hydrologic cycle.

Hyetograph - graph of rainfall intensity versus time.

Impervious - a surface through which little or no water will move. Impervious areas include paved parking lots and roof tops.

Infiltration Capacity - rate at which water can enter soil with excess water on the surface.

Interflow - flow of water through the upper soil layers to a ditch, stream, etc.

Intermittent Stream - a stream that flows only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year. See also ephemeral and perennial streams.

Invert - bottom of a channel or pipe.

Knickpoint - a point of abrupt change in bed slope. If the streambed is made of erodible material, the knickpoint, or downcut, may migrate upstream along the channel and have undesirable effects, such as undermining bridge piers and other manmade structures.

Lag Time - time from the center of mass of the rainfall to the peak of the hydrograph.

Low Impact Development (LID) - a comprehensive design and development technique that strives to mimic pre-development hydrologic characteristics and water quality with a series of small-scale distributed structural and non-structural controls.

Losses - rainfall that does not runoff, i.e. rainfall that infiltrates into the ground or is held in ponds or on leaves, etc.

Low Flow - minimum flow through a watercourse which will recur with a stated frequency. The minimum flow for a given frequency may be based on measured data, calculated using statistical analysis of low flow data, or calculated using hydrologic analysis techniques. Projected low flows are used to evaluate the impact of discharges on water quality. They are, for example, used in the calculation of industrial discharge permit requirements.

Morphology, Fluvial - the study of the form and structure of a river, stream, or drain.

Nonpoint Source Pollution - pollutants carried in runoff characterized by multiple discharge points. Point sources emanate from a single point, generally a pipe.

Overland Flow - see Runoff.

Peak Flow - maximum flow through a watercourse which will recur with a stated frequency. The maximum flow for a given frequency may be based on measured data, calculated using statistical analysis of peak flow data, or calculated using hydrologic analysis techniques. Projected peak flows are used in the design of culverts, bridges, and dam spillways.

Perched Ground Water - unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone.

Perennial Stream - a stream that flows continuously during both wet and dry times. See also ephemeral and intermittent streams.

Precipitation - water that falls to earth in the form of rain, snow, hail, or sleet.

Rating Curve - relationship between depth and amount of flow in a channel.

Recession Curve - portion of the hydrograph where runoff is from base flow.

Retention - practices which capture stormwater and release it slowly though infiltration into the ground. See also detention.

Riparian - pertaining to the bank of a river, pond, or small lake.

Runoff - flow of water across the land surface as surface runoff or interflow. The volume is equal to the total rainfall minus losses.

Runoff Coefficient - ratio of runoff to precipitation.

Runoff Curve Number - parameter developed by the Natural Resources Conservation Service (NRCS) that accounts for soil type and land use.

Saturated Zone - (1) those parts of the earth's crust in which all voids are filled with water under pressure greater than atmospheric; (2) that part of the earth's crust beneath the regional water table in which all voids, large and small, are filled with water under pressure greater than atmospheric; (3) that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Scarp - the sloped bank of a stream channel.

Sediment - soil fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice.

Sinuosity - the ratio of stream length between two points divided by the valley length between the same two points.

Simulation Model - model describing the reaction of a watershed to a storm using numerous equations.

Soil - unconsolidated earthy materials which are capable of supporting plants. The lower limit is normally the lower limit of biological activity, which generally coincides with the common rooting of native perennial plants.

Soil Moisture Storage - volume of water held in the soil.

Storage Delay Constant - parameter that accounts for lagging of the peak flow through a channel segment.

Storage-Discharge Relation - values that relate storage in the system to outflow from the system.

Stream Corridor - generally consists of the stream channel, floodplain, and transitional upland fringe.

Subbasins - hydrologic divisions of a watershed that are relatively homogenous.

Synthetic Design Storm - rainfall hyetograph obtained through statistical means.

Synthetic Unit Hydrograph - unit hydrograph for ungaged basins based on theoretical or empirical methods

Thalweg - the "channel within the channel" that carries water during low-flow conditions.

Time of Concentration - time at which outflow from a basin is equal to inflow or time of equilibrium.

Transpiration - conversion of liquid water to water vapor through plant tissue.

Tributary - a river or stream that flows into a larger river or stream.

Unit Hydrograph - graph of runoff versus time produced by a unit rainfall over a given duration.

Unsaturated Zone - the zone between the land surface and the water table which may include the capillary fringe. Water in this zone is generally under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

Vadose Zone - see Unsaturated Zone.

Watershed - area of land that drains to a single outlet and is separated from other watersheds by a divide.

Watershed Delineation - determination of watershed boundaries. These boundaries are determined by reviewing USGS quadrangle maps. Surface runoff from precipitation falling anywhere within these boundaries will flow to the waterbody.

Water Surface Profile - plot of the depth of water in a channel along the length of the channel.

Water Table - the surface of a groundwater body at which the water pressure equals atmospheric pressure. Earth material below the groundwater table is saturated with water.

Yield (Flood Flow) - peak flow divided by drainage area